Technical Memorandum

Grasse River Project
2004/2005 River Ice Monitoring
Documentation Summary

Submitted on behalf of Alcoa Inc.

December 2005
(Revised April 2006)

Table of Contents

List of Tables

List of Figures

List of Appendices

1.0 Introduction

The Grasse River flows to the northeast approximately 55 miles from a dam located at Pyrites, New York to its confluence with the St. Lawrence River approximately 7 miles east of Massena, New York. A topographic map of the lower 16 miles of the river is illustrated in **Figure 1**, and a profile of the normal water surface elevations along the 55-mile length of the river is provided as **Figure 2**. The "lower Grasse River" is the reach beginning downstream of the old power canal in the Village of Massena, where remediation options are being studied to address PCB contamination in the sediments.

In March 2003, an ice jam formed in the lower Grasse River that resulted in the scouring of a portion of the bed sediments. During the winters of 2002/2003 and 2003/2004, observations were made of the ice formation and breakup process on the river. As in those previous winters, monitoring has been conducted to document ice formation and breakup during the winter of 2004/2005. The monitoring was conducted as specified in the *2004/2005 Grasse River Monitoring Work Plan* (Alcoa, January 2005); the information gathered is summarized in this technical memorandum. The memorandum includes an analysis of the available data and conclusions regarding the potential for an ice jam event to have disturbed the river sediments in the lower Grasse River during the 2005 spring breakup.

Field observations and data were gathered largely by Camp Dresser & McKee (CDM), and supplemented with aerial inspection and photography by Andrew M. Tuthill of the US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory (CRREL). Additional information was supplied by Clarkson University who modeled the formation and decay of ice in the lower Grasse River. The results of sediment elevation surveys conducted in July-September 2004 and April-May 2005, as provided by Quantitative Environmental Analysis (QEA), have also been used in the formation of conclusions. The results and conclusions of this memorandum were reviewed and accepted by a team of ice experts that include Mr. Tuthill (see above), Dr. Hung Tao Shen of Clarkson University, Dr. George Ashton, (CRREL, retired), and Guenther Frankenstein (CRREL, retired).

2.0 Climatological Conditions

The climatological data used for this study were taken from the Massena International Airport. The daily maximum and minimum temperatures during the winter of 2004/2005 are shown in **Figure 3.** Average temperatures remained below freezing for all but 13 days between December 1, 2004 and March 24, 2005. As shown in Figure 3, there were two significant freezing periods in mid-January and late February / early March. From January 15, 2005 until February 2, 2005, the maximum daily temperatures did not exceed freezing (32 degrees Fahrenheit [^{o}F]). This period of cold was followed by more seasonal temperatures until February 17, 2005. The second significant freezing period began February 17, 2005 and ended March 13, 2005. Average temperatures fluctuated near freezing until March 27, 2005 when the air temperature warmed considerably and highs up to 64^{o}F were observed on March 31, 2005.

Daily precipitation data during the winter of 2004/2005 are shown in **Figure 4.** Due to the various forms of winter precipitation (i.e., snow, or ice rain), on many occasions the amount of precipitation cannot be measured accurately and is reported as "trace". The most significant rain event occurred on April 2, 2005, one day prior to ice breakup, and was reported to be 1.09 inches.

3.0 River Stage Monitoring

3.1 River Stage During Ice Formation

Provisional real-time stage height and flow (discharge) data for the USGS gauging station at Chase Mills (#04265432) were downloaded for the period of December 1, 2004 to April 7, 2005 from the USGS website (**Figure 5**). The gauge is located approximately 11 miles upstream of Massena and has been in operation since the end of 2003. As shown in Figure 5, flow is not calculated and reported by USGS during periods when ice is present, due to ice-related backwater effects. This is common among stream gauging stations in the northern U.S. This has occurred during both 2003/2004 and 2004/2005 winters and will likely occur in future winters.

Based on Figure 5, the daily average river flow was approximately 3,040 cubic feet per second (cfs) on December 13, 2004, when a complete ice cover was first observed in the lower river.

Stage height readings at Alcoa's Outfall 001 gauge are shown on **Figure 6**, for the December 1, 2004 to April 7, 2005 timeframe. These same stage height data are also shown in Figure 3, in comparison to daily air temperatures. Outfall 001 is located approximately 1,250 feet downstream of the Alcoa Bridge. The stage height information is automatically recorded every five minutes at this station throughout the year, and downloaded by the Alcoa Massena Operations ChemLab for data storage. For reference, the monthly stage height data from February 2004 through December 2005 are included electronically in **Appendix A**. No data were available, however, for January, October, and November of 2004. These data were inadvertently lost in the archiving process.

As shown in Figure 3 and Figure 6, the stage height at Outfall 001 displayed unusual spikes on several instances between January 18 and January 30, 2005. Similar fluctuations were observed around December 20-22, 2004 and between February 23 and March 2, 2005. These spikes coincide with the coldest air temperatures measured in the winter season. The extreme fluctuations in stage height during these periods were believed to be the result of either frozen water in the vicinity of the gauge or short term malfunctioning of some of the gauge components due to the severe temperatures and, thus, not representative of typical conditions. A close examination of these data spikes indicates variations of 2 to 3 feet sometimes within 15 to 30 minute time intervals.

During the monitoring periods in question, the river had an intact ice cover and therefore water surface elevation variations of this magnitude were not physically possible. An alternative representation of the Outfall 001 stage data is presented in Figure 4, as daily average stage height. This representation lessens the impact of short-term fluctuations.

Based on Figure 4, the stage height was approximately 5.53 feet on December 13, 2004, when a complete ice cover was first observed in the lower river.

3.2 River Stage During Ice Breakup

To evaluate river stage during the spring breakup period, the stage height and flow data for the USGS gauging station at Chase Mills were downloaded for the period of March 31 to April 5 (**Figure 7**). The flow rose from about 5,000 cfs mid afternoon on April 2 to a maximum of about 8,500 cfs late in the afternoon of April 4, after which the flow declined. At noon on April 3 the flow at Chase Mills was about 7,500 cfs. These flow increases are largely associated with a 1.09 inch rainfall, as measured at the Massena International Airport, which occurred between 12:00 am on April 2 and 12:00 am on April 3. This was by far the most significant 24-hr precipitation event during the month prior to the clearing of ice from the river. The next highest 24-hr precipitation event was 0.35 inches on March 7, 2005.

Stage height readings at Alcoa's Outfall 001 gauge are also shown on Figure 7. The stage record indicated that from April 1 to noon of April 3 a noticeable increase in stage of about 2.0 to 2.8 feet (from about 5.5 feet to 8.3 feet) was observed. The stage then proceeded to decline steadily.

4.0 Monitoring of River Ice Formation and Extent

The extent of ice cover on the Grasse River was monitored periodically at the 17 locations shown in Figure 1. A listing of the monitoring locations is included as **Table 1**. Dated photographs looking both upstream and downstream were taken at each location, as included in Appendix A. The photographs are numbered to correspond with the locations shown in Figure 1. Monitoring was performed once a month beginning in early December and more frequently when the ice cover began to deteriorate in late March 2005.

The lower Grasse River below the Alcoa Bridge (from transect T2 to approximately transect T66) was fully covered with ice by December 13, 2004, with the exception of the immediate vicinity of Outfall 001. In the lower river, ice cover extended to the center of the river through a combination of thermal border ice growth and juxtaposition of frazil ice slush and flow arriving from the steeper, faster flowing upstream reaches. This is the typical mode of ice formation in areas of the Grasse River that have low flow velocities. In these areas of the river, the ice remains stationary through the winter with little to no visible distortion.

In areas of the river with rapids or sharp drops in elevation, namely within Massena, Louisville, and Chase Mills, the ice takes longer to form and typically does not completely cover the river. The mode of ice formation is similar to that described above.

5.0 Ice Thickness Measurements and Simulation

Ice thickness measurements were collected in January and February 2005 to document the intact ice cover thickness in the lower Grasse River during the mid-winter period. Thickness measurements were also collected at two upper Grasse River locations. Attempts were made to collect additional thickness measurements in March, nearer to the time of breakup. However, thin or unformed ice near the river access points created safety concerns that prevented crews from accessing the ice.

On a trial basis, Alcoa utilized a computer simulation model to forecast ice formation and decay during the winter 2004/2005 period. The model was developed and run by Clarkson University. The model uses actual and forecasted climatological data, as collected from the Massena Airport.

The ice thickness measurement data and ice thickness simulations are presented in the following subsections.

5.1 Ice Thickness Measurements

A motorized auger was utilized to bore 8-inch diameter holes in the ice. A tape measure or graduated probe was used to hook onto the bottom of the ice cover and measure upward to the top of the borehole. Using visual observations of the borehole, the total depth of material was differentiated between solid ice and porous snow cover or slush. A single borehole was augered through the ice on January 21, 2005 at the Amvets monitoring station near river transect T66 (location #1 on Figure 1), where the solid ice cover thickness was measured as 14 inches.

A cross section of ice thickness was taken on February 24, 2005 along a 250 foot transect from the north shore near Outfall 001. The results are summarized in the following table:

Ice Thickness Cross-Section at Outfall 001 February 24, 2005	
Distance From North Shore (feet)	Ice Cover Thickness (inches)
36	16
72	13
108	10.5
126	11
144	11
180	20
216	24
252	26
Average (near center)	23.3

The presence of snow slush was noted overtop of the solid ice at this location. The measurement of "ice cover thickness" above is the total thickness of the solid ice cover, which includes clear or black ice, frozen frazil, and snow ice. The thickness measurements closer to the north shore at this location are believed to be influenced by the warmer water discharging through Outfall 001. Therefore, an average thickness was calculated (23.3 inches) from the three boreholes drilled closest to the center of the channel (i.e., at distances of 180, 216 and 252 feet from the northern shore).

Between February 24 and 28, 2005 ice thickness measurements were taken near the following monitoring locations noted on Figure 1: Amvets (1), Route 131 Bridge (4), Outfall 001 (6), Route 37 Bridge (10), and the Madrid Bridge (15). The measurements at these locations are as follows:

Ice Thickness Measurements – February 24 -28	
Location (Number) and Distance from Shore	**Ice Cover Thickness (inches)**
Amvets (1) – 120 feet from north shore	20.5
Route 131 Bridge (4) – 120 feet from north shore	19
Outfall 001 (6) – 255 feet from north shore	26
Route 37 Bridge (10) – 100 feet from north shore	20
Madrid Bridge (15) – upstream of bridge in Madrid Park, 120 feet from shore	14

Additional ice thickness measurements were obtained from the Blasland, Bouck & Lee (BB&L) field crew during bulk sediment sample collection for use in the Remedial Options Pilot Study (ROPS) treatability studies. The ice thickness measurements were performed February 28 through March 2, 2005 between river transects T7 and T8. Eight auger holes were drilled in a rectangular grid in the center of the river, originating along transect T7 (T7-1 through T7-8 below). These eight boreholes were configured in two columns spaced 20 feet apart, and boreholes drilled at 20-foot intervals progressing downriver. A ninth borehole (T8 below) was drilled in the center of the river at transect T8, approximately 440 feet downstream.

Ice Thickness Measurements-February 28 – March 2	
Location	Ice Cover Thickness (inches)
T7-1	21
T7-2	21
T7-3	23
T7-4	22
T7-5	24
T7-6	23
T7-7	24
T7-8	23
T8	21
Average	22

Transects T7 and T8 are located approximately 1,500 and 2,500 feet downstream of Outfall 001, respectively.

5.2 Ice Thickness Simulations

As discussed in the hindcasting analysis provided in Section 4 of the *Draft Addendum to the Comprehensive Characterization of the Lower Grasse River* (Alcoa, April 2004), mechanical ice breakup and ice jams could be expected to occur in the lower Grasse River when the discharge increase from freezeup to breakup exceeds 3,500 cfs, and the ice thickness at the time of breakup is larger than approximately 15 inches. Reaching these conditions would not necessarily mean that ice jams sufficient to create sediment disturbance will form, but these conditions are considered to be the threshold of concern. Forecasting of temperature, rainfall, and ice thickness in a given year can help to predict whether these threshold conditions may be met during the breakup period. These forecasts can also help determine when a mechanical breakup may occur, and could be useful in the event that a feasible interim ice management option (e.g. ice breaking) is identified for the river.

Throughout the latter part of the winter, the growth and decay of the ice cover thickness was simulated by Clarkson University using actual and forecasted air temperature data from the Massena Airport. Together with river flow and/or rainfall data, the simulated ice thickness can potentially be used to predict the time of ice breakup and whether a mechanical ice breakup is likely to occur. Mechanical ice breakup in the upper Grasse River can lead to ice jams in the lower river, if an intact ice cover of sufficient strength exists in the lower river which would prevent the continued movement of ice floes entering the lower river from upstream. Clarkson conducted the simulations on a trial basis for the winter of 2004/2005.

Clarkson applied a forecasting methodology using the "unified degree method", similar to the winter "hindcasting" analysis included as Appendix N of the *Draft Addendum to the Comprehensive Characterization of the Lower Grasse River* (Alcoa, April 2004). Rather than using climate data to retroactively predict ice cover thickness at the time of breakup in a given year, Clarkson used the actual and forecasted 2004/2005 temperature data to predict the ice cover thickness through its growth and decay. The thickness simulation generally applies to the stable "pools" of the river, not the area of rapids. Clarkson's methods and results are discussed in the report entitled *Grasse River Ice Cover Forecasting – Winter 2004/2005*, which is included as **Appendix B** to this memorandum.

Cover thickness simulations were started on January 27 and continued through March 31, 2005. A 15-day air temperature forecast was periodically uploaded into the model to generate a graph showing predicted ice cover thickness in relationship to the winter calendar. As the winter progresses, the "predicted thickness" portion of the curve is replaced by a "simulated thickness", based on the actual temperatures that occurred. A simplified example of the simulated and predicted ice thickness as of February 22, 2005 is provided as **Figure 8**. As shown in Figure 8, a single measured ice thickness of 14 inches collected on January 21 matched favorably with the simulated thickness.

Figure 9 shows the results of the last simulation for winter 2004/2005, using actual temperature data of March 31, 2005 and the weather forecast for the subsequent 15 days. The maximum simulated ice thickness reached 26.6 inches by March 27, before it started to decay. Beginning on or about March 29, warm air temperatures were predicted to cause a rapid decrease in ice thickness. The ice thickness was forecasted to be 8.8 inches on April 3, with complete melt-out by April 6 (unless a mechanical breakup were to occur). This roughly correlates to the visual observations made of the breakup period (see Section 6 below), which documents ice movement during the daylight hours on April 3, after a 1.09 inch rainfall event that occurred from midnight April 2 to midnight April 3. This significant rain event during the rapid decay of the ice created a mechanical breakup and ice run, which was visually documented. The hindcasting analysis conducted by Clarkson in 2004 (Alcoa, April 2004) concluded that significant breakup ice jams in the lower Grasse River occur when the ice cover thickness is greater than 15 inches at the time of breakup. Based on this criterion and the forecasted ice thicknesses on April 2 and 3 (10.5 to 8.8 inches), the mechanical breakup that occurred on or around April 3 would be unlikely to create a significant ice jam.

The periodic ice thickness measurements made during the winter are also shown on Figure 9. For the measurements made at Outfall 001 on February 24, the average of the three locations nearest to the center of the river is plotted on Figure 9. Likewise, a single point representing the average of the nine measurements made between transects T7 and T8 is shown on Figure 9. Thickness measurements made in the lower river are shown in green; the upper river in blue. The actual thickness measurements are generally consistent with the simulated thicknesses, with the exception of the measurements at the Madrid Park, which is approximately 25 miles upstream (and south) of Massena.

6.0 Monitoring of River Ice Breakup

The monitoring of the Grasse River intensified at the end of March as air temperature began to increase and rainfall was anticipated. Prior to the complete breakup of ice, an aerial site reconnaissance was performed and photographs of ice cover decay were observed. During breakup, field crews were stationed along the Grasse River to visually observe the ice breakup event.

Subsections 6.1 and 6.2 below document the pre-breakup observations (aerial survey) and the field observations during breakup, respectively. After collection and review of the breakup data, the 2005 breakup conditions were compared with those of the 2003 breakup, when a significant ice jam was observed (Subsection 6.3).

6.1 Pre-Breakup Observations

On March 31, Andy Tuthill of CRREL made an over flight of the Grasse River and provided both a written summary and oblique aerial photographs of the ice cover, as presented in **Appendix C**. These observations are incorporated by reference to this memorandum, and have been factored into its conclusions. A brief summary of those observations is included below.

> The St. Lawrence River was for the most part open water at the mouth of the Grasse River. From the mouth of the Grasse River upstream to the old power dam (just upstream of transect T1) the ice cover was intact and consisted of dark-colored decayed ice. The river was open from the old power dam upstream through Massena to about 1 mile downstream of the Route 37 Bridge. From there on upstream to the foot of the Louisville rapids the river was ice covered. From just downstream of the Louisville Bridge to a point about ½ mile upstream of the bridge the river was open, and upstream from that point the ice cover was approximately ½ ice covered and ½ open water. Further upstream the river had stretches of open water and ice cover.
>
> In general, the ice that remained on the river by March 31 appeared dark in color and decayed due to the previous 2½ weeks of above freezing daytime air temperatures and exposure to the sun.

6.2 Field Observations During Breakup

With significant rain and higher temperatures predicted for the weekend of April 2 and 3, 2005, CDM mobilized field crews to intensify its monitoring of river ice conditions. Observations by the field crews[1] are summarized below for the April 2 to April 4, 2005 timeframe, during which the spring breakup occurred. The observations specific to the lower Grasse River are also illustrated in **Figure 10**. Video documentation of final stages of ice breakup is included on a DVD in Appendix A.

[1] Field observations were recorded and summarized by Jamie Murray and Derek Wintle of the CDM Massena office, in consultation with other CDM field crew members.

April 2, 2005 - Observations of the ice cover in the lower Grasse River at 10:30 pm on Saturday April 2 showed only minor movement of the upstream edge of ice cover near the old power canal dam to about 100 feet downstream.

April 3, 2005 - On Sunday morning, April 3, ice accumulations were observed at two locations. The first location was situated downstream of the Alcoa Bridge at approximately transect T3 to T5, as shown in **Figure 11a**. This small accumulation was the result of an earlier breakup of an ice sheet upstream of the Alcoa Bridge, and was formed some time before 8:30 am. The second location was situated just downstream of the Chase Mills Bridge (10 miles upstream of Massena), and extended for approximately ½ mile. The field crew did not reach this location until about 10:30 am, so the exact time the accumulation formed is not known.

Around 10:00 am, there was a movement of ice that passed under the Main Street Bridge and into the lower Grasse River. The ice then traveled under the Alcoa Bridge and began accumulating at approximately transect T3, adding to the earlier accumulation. Based on field observations, the extent of ice floe indicated that the majority of the ice still remained upstream. The accumulations of ice at transect T3 extended to approximately transect T5.5.

Around 1:50 pm, there was another movement of ice into the lower Grasse River as illustrated looking upstream from the Alcoa Bridge in **Figure 11b**. This second ice floe had a much longer duration of approximately 45 minutes and contained a larger concentration of ice and debris (e.g. branches, trees, etc.) than the previously observed morning ice floe, as shown in **Figure 11c**. It is believed that this second run of ice originated at the accumulation area below Chase Mills, as viewed earlier that day. The ice began to accumulate against the remnants of the previous ice floe at transect T3, consequently causing the accumulation to extend upstream. As the tail of the accumulation approached transect T3, the entire jam began to move collectively downstream. The ice floe continued downstream until it encountered an intact ice sheet at approximately transect T9.5. At this time, the accumulation of ice extended approximately from transects T3 to T9.5 and the ice sheet retaining the accumulation extended approximately from transects T9.5 to T15. The accumulation of ice remained in place until nightfall. Extensive photographs were taken.

April 4, 2005 - On Monday morning April 4 at daybreak, the ice sheet preventing the movement of the ice accumulation between transects T3 to T9.5 of the previous day had partially broken off, and from approximately transect T12.5 to T20 the river was free of ice. There was evidence of ice movement overnight. The exact location of the remaining ice accumulation was not clearly defined due to the presence of heavy fog; however, it was estimated to extend between transects T10.5 to T12.5.

Around 10:30 am, the accumulation remaining below the Alcoa Bridge collectively continued to flow downstream towards the Route 131 Bridge. There was still an ice sheet remaining upstream of the Route 131 Bridge from about transects T21 to T22.5. This ice sheet prevented the ice floe from passing under the bridge, and ice was forced to accumulate approximately from transects T19 to T21. Photographs were taken including video footage of the ice floe throughout this section of the river.

Around 11:00 am, the accumulation began to breakup and drifted downstream to Massena Center. Due to limited access (private property) to the Grasse River downstream of Massena Center (location 3), it was difficult to determine the exact location of the accumulation, therefore field activities ceased at 2:45 pm. Since the lower Grasse River was clear of ice near Haverstock Road (location 2) and clearing out at Amvets (location 1), it was assumed that the lower Grasse River was free of ice by late afternoon on April 4, 2005 with the exception of minor ice floes from the clearing of location 3.

The breakup conditions described above and viewed through photographs and video documentation did not indicate any significant potential for an ice jam that would produce a significant bed scouring event.

6.3 Comparison with the 2003 Ice Jam

The numerical simulations of the 2003 ice jam event, as shown in Appendix N of the *Draft Addendum to the Comprehensive Characterization of the Lower Grasse River* (Alcoa, April 2004), provide some guidance towards estimating the severity of the ice accumulation in the 2005 event. The river discharge was similar in each event. However, the ice supply was of much shorter duration in 2005 (approximately 0.75 hours in 2005 vs. 25 hours in 2003), and the predicted ice cover thickness at the time of breakup was much thinner (8 to 10 inches in 2005 vs. 24 inches in 2003). The simulations conducted for the 2003 event included interim calculations of stage and ice jam thickness at 5 and 10 hours after the beginning of the ice supply. The 2003 modeling results are summarized as follows:

- at 5 hours, increase in stage at T1 was approximately 3.0 feet, and the maximum predicted jam thickness was about 9.75 feet;
- at 10 hours, increase in stage at T6 was approximately 3.25 feet, and maximum jam thickness was about 15 feet.

In 2005, the ice supply lasted only about 0.75 hours. Accordingly, it is expected that the maximum thickness of the jam (and therefore upstream stage rise) was well below that of 2003. Simple linear extrapolation of the 2003 simulated jam thicknesses from 10 to 5 to 0.75 hours yields a jam thickness of about 5 feet. An ice jam thickness of 5 feet would be approximately 10 feet above the river bottom, and would therefore not be expected to create the under-ice velocities required to cause a significant scour event.

Based on the extrapolation from 2003, a 5 feet ice jam thickness would be expected to produce a stage rise of about ¼ to ⅓ of the ice jam thickness, or about 1.3 to 1.65 feet. During the ice run on April 3, 2005 that extended to transect T9.5 (Figure 10), an increase in stage height of only about 1 foot was observed at Outfall 001 (Figure 7). From April 2 through April 4, which included a 1.09 inch rainfall on April 2, an overall stage rise of 2 to 3 feet above normal river stage was observed. As a point of comparison, an approximate 9 feet rise above normal river stage was observed at Outfall 001 during the 2003 ice jam event.

Based on comparison to 2003, the ice accumulations that occurred in the lower Grasse River on or around April 3 and 4 are unlikely to have created a significant ice jam or bed scouring event.

7.0 Comparison of Sediment Elevation Measurements

Sediment elevation measurements were made between sediment probing transects T6.75 and T9.5 in July-September 2004 and April-May 2005 as part of baseline monitoring for the ROPS. Coincidentally, this area roughly correlates to the leading edge of the largest concentration of broken ice accumulation observed during the spring 2005 breakup (Figure 10). For these sediment surveys, measurements were collected along a 25-ft by 25-ft grid in the main channel and a 25-ft by 10-ft grid along the side slopes and in the near shore area (**Figure 12**). Total water depth and water surface elevation measurements were obtained at each grid node using a differential global positioning system (DGPS). From this information, the sediment surface elevation was calculated. A total of 817 sediment elevation measurements were obtained during each survey.

Sediment elevation information from the two surveys was compared to investigate any potential changes to the river bottom. Elevations were paired by location (measurements in 2004 were generally within 2 to 3 feet laterally of measurements in 2005), and differences were calculated on a point-by-point basis for the main channel area; comparisons were not performed for the near shore and side slope areas because positioning inaccuracies have a more significant impact in these areas due to the rapid change in sediment elevations that occur over short distances.

The elevation comparisons in the main channel, which are shown in **Figure 13**, indicate changes that may exceed what is expected from measurement error. Although increases and decreases in elevation are intermixed to some extent, there is a clear tendency toward decreases in elevation (suggesting erosion) between T7 and T9 and increases in elevation (suggesting deposition) downstream of T9.

In an effort to understand how much of these apparent changes may be due to measurement error derived from horizontal positioning differences between the paired 2004 and 2005 measurements, and error in the measurement of elevation (i.e., vertical inaccuracy), the changes between 2004 and 2005 were compared to changes measured between replicate surveys conducted in July-September 2004 in order to estimate measurement error. These replicate surveys are described in the *2004 Remedial Options Pilot Study Baseline Monitoring Summary Report* (Alcoa 2005). **Figure 14** shows the distributions of differences between paired elevation measurements for the replicate 2004 surveys and the 2004 and 2005 survey comparison. The replicate 2004 data differences, which are shown by solid circles, appear to be normally distributed with a median of about zero with 95 percent of the values between -0.5 feet (decrease) and +0.5 feet (increase). In contrast, the differences between the paired 2004 and 2005 measurements, which are shown by open triangles, have a distribution that deviates from normality at the tails, has a median value of about -0.2 feet (decrease) and 95 percent of the values between -1.5 feet (decrease) and +1.1 feet (increase). Thus, it appears that some erosion and deposition occurred between the 2004 and 2005 surveys. Overall, the replicate measurements that indicate a decrease in elevation differ, on average by about -0.3 feet while those that indicate an increase in elevation differ, on average, by +0.3 feet. Comparable statistics from the 2004 to 2005 elevation differences are 0.5 feet for both areas of apparent erosion and deposition. Thus, on average, the 2004 to 2005 changes are about 0.2 feet greater than might be expected due to measurement error.

The small ice jam that formed in the river at about T9.5 and extended upstream to about T3 (see Section 6.2) may have resulted in sufficient bottom shear stress to cause limited sediment movement. Given the estimated ice thickness of 5 feet and a river flow of about 8,500 cfs at the time of the jam, the velocity under the jam was estimated to be about 2 feet per second. The bottom shear stress generated by this velocity and the vertical turbulence caused by the rough underside of the ice (as estimated based on the analysis described in *Evaluation of Bottom Shear Stress Underneath an Ice Jam in the Lower Grasse River,* Alcoa 2004) averaged about 2 Pa and probably ranged from about 0.3 to 10 Pa. This range of shear stresses equates to erosion potentials (based on site-specific sediment shaker data presented in the *Comprehensive Characterization of the Lower Grasse River,* Alcoa 2001) of 8 to 31 mg/cm^2, which would be expected to result in some, albeit likely minor, bed erosion.

Regardless of the cause of the apparent erosion and deposition, this sediment movement should have had limited, if any, impact on PCB levels in the river since only a small area of the river appears to have been impacted, and PCB levels in the potentially affected sediments in this area of the river are relatively low (4.5 ppm in the surface sediments, 9 ppm in the top foot, and 17 ppm in the top 1.5 feet).

8.0 Summary and Conclusions

Periodic visual observations were made of the lower 45 miles of the Grasse River during the winter of 2004/2005, and a photographic record developed from observations at 17 locations. The lower Grasse River below the Alcoa Bridge (from transect T2 to approximately transect T66) was fully covered with ice by December 13, 2004, with the exception of the immediate vicinity of Outfall 001. No mid-winter breakup was observed in 2005. The results of ice thickness simulation modeling also did not indicate any evidence of a mid-winter breakup.

Ice thickness measurements were made at eight locations during the mid-winter period, with the maximum ice cover thickness measured as 26 inches on February 28, 2005. The growth and decay of the ice cover was numerically simulated during the winter of 2004/2005 using a model developed and run by Clarkson University. The results of the ice thickness simulations generally compare favorably with the actual thickness measurements. The model predicted a maximum ice cover thickness of 26.6 inches by March 27, before it started to decay. Beginning on or about March 29, warmer air temperatures were predicted to cause a rapid decrease in ice thickness. An aerial reconnaissance conducted on March 31 observed a general deterioration of the ice cover in the upper reaches of the river, as well as large stretches of open water. The ice thickness was forecasted to be 8.8 inches on April 3, with complete melt-out by April 6 unless a mechanical breakup were to occur. This roughly correlated to the visual observations made of the breakup period.

Ice cover on the Grasse River began to deteriorate in late March due to increased air temperatures. Areas of the river with swifter moving water, namely between the Alcoa Bridge and Outfall 001, were clear of ice in early March. Ice remained in the river downstream of the Massena Power Canal through March 27, 2005, when the ice cover began to deteriorate rapidly due to elevated air temperatures and an increase in water flow. Ice cover deterioration continued through April 2, 2005. A significant rainfall event took place between April 2 and April 3, 2005, which was responsible for a substantial clearing of ice from the Grasse River. The river was observed to be clear of ice on April 4, 2004.

It appears from photographs and eyewitness accounts that a minor ice run/jam occurred in the lower Grasse River during the 2005 spring breakup. The term minor ice run/jam is a qualitative description of an accumulation of ice pieces. For the purpose of the present study, a minor ice run/jam does not result in thickness sufficient to cause a significant disturbance to the underlying sediments (relative to the 2003 event). In addition, the duration of the minor ice run/jam is short enough such that it is also indicative of a limited supply of ice. Information used to classify the 2005 breakup event as a minor ice jam include:

- *Ice Jam Thickness* – As discussed in Section 6.3, the ice supply in 2005 was of a much shorter duration in comparison to 2003. Based on a comparison between observed and simulated jamming for the 2003 severe event, the likely thickness of the jam in 2005 (at or near transect T9.5) was probably on the order of 5 feet. The toe of such a jam would be approximately 10 feet above the river bottom, assuming the typical depth of 15 feet at this location in lower Grasse River.

- *Ice Cover Thickness at Time of Breakup* – Based on the simulated ice cover thickness forecasted by Clarkson, the ice cover thickness on April 3 during breakup was approximately 8.8 inches. In 2003, when a severe ice jam occurred, the "hindcasted" ice thickness at breakup was 24 inches. As concluded in a previous report (Alcoa, April 2004), severe ice jams associated with significant bed scour are believed to occur when ice cover thickness at breakup is at least 15 inches.

- *Outfall 001 Stage Height During the Jam* - During the ice run/jam on April 3, 2005, an increase in stage height of only about 1 foot was observed. For the breakup period of April 2-4, an overall stage rise of 2 to 3 feet above normal river stage was observed. In comparison, an approximate 9 feet rise above normal river stage was observed at Outfall 001 during the 2003 ice jam event. Based on comparison to 2003, the ice accumulations that occurred in the lower Grasse River on or around April 3 and 4 are unlikely to have created a significant ice jam.

Sediment elevation data collected in July-September 2004 and April-May 2005 were compared to investigate potential effects of the minor ice run/jam observed in 2005. This comparative sediment elevation data were not originally developed with the intention of evaluating breakup conditions, but for establishing baseline sediment elevations as part of the ROPS. These comparisons indicated both decrease (suggesting erosion) and increases (suggesting deposition) in elevation, with an average increase or decrease of approximately 0.5 feet. Comparison of replicate measurements from the July-September 2004 survey indicates approximately 0.3 feet of this difference could be expected due to normal measurement error. Therefore about 0.2 feet of this measured change between September 2004 and April 2005 could be attributed to actual movement of material.

In response to the results of sediment elevation comparisons, a more detailed evaluation was conducted on the potential under ice velocities and shear stress that could have been generated during the minor ice run/jam. Based on the instantaneous maximum river flow during the jam (8,500 cfs) and an estimated ice thickness of 5 feet, erosion potentials of 8 to 31 mg/cm^2 could have been generated, which would be expected to result in some bed erosion, although likely minor.

The fact that no other known mechanism could have resulted in the movement of sediment between September 2004 and April 2005, coupled with the coincidence of ice accumulation in the vicinity of where sediment elevation differences were observed, suggests that the ice accumulation in this area in 2005 may have caused a minor ice jam and resulted in some minor bed erosion. However, regardless of the cause of the apparent erosion and deposition, this sediment movement should have had limited, if any, impact on PCB levels in the river since only a small area of the river appears to have been impacted, and PCB levels in the potentially affected sediments in this area of the river are relatively low (4.5 ppm in the surface sediments, 9 ppm in the top foot, and 17 ppm in the top 1.5 feet).

9.0 References

Comprehensive Characterization of the Lower Grasse River (Alcoa, 2001)

Draft Addendum to the Comprehensive Characterization of the Lower Grasse River (Alcoa, April 2004)

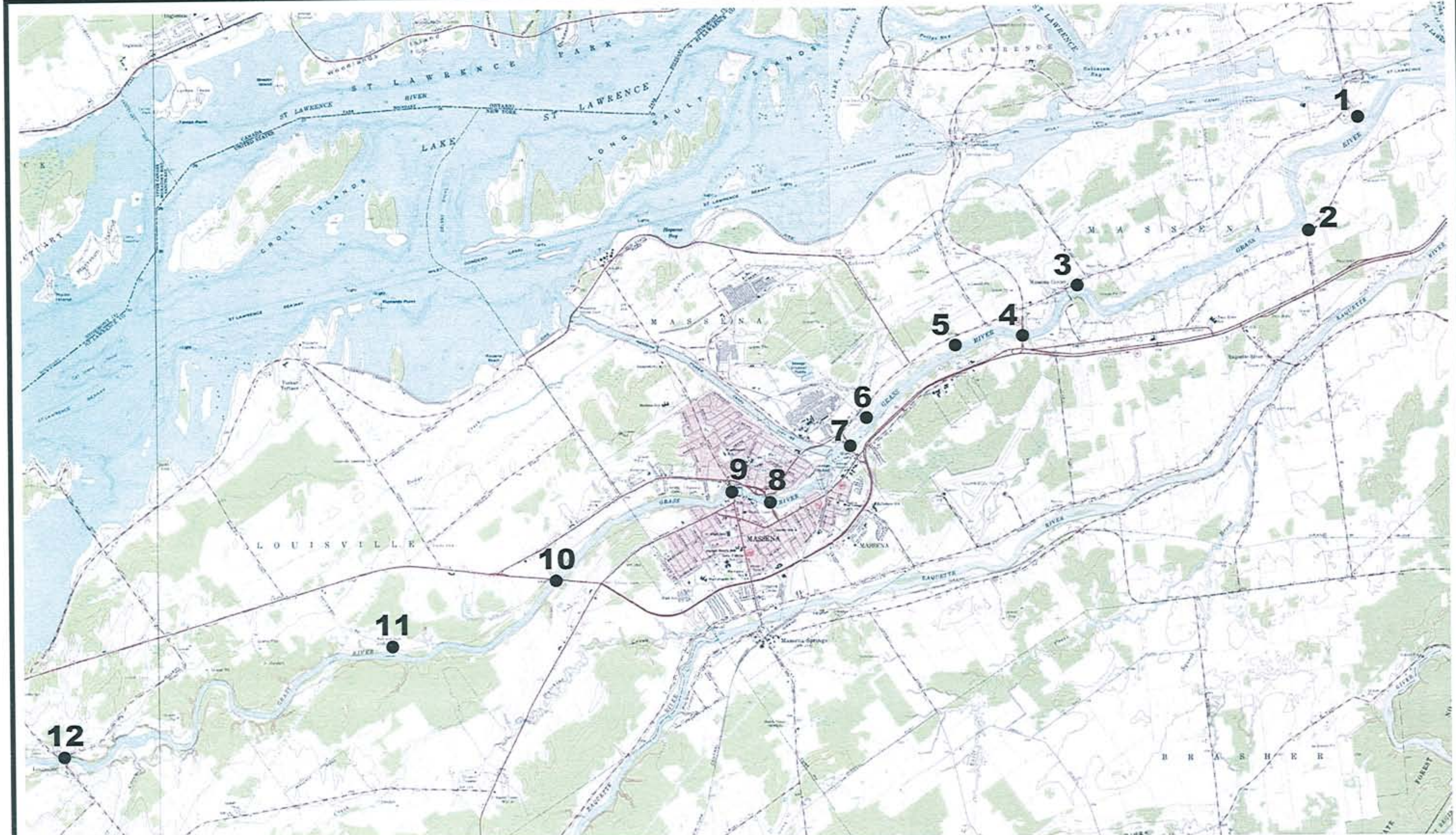
Evaluation of Bottom Shear Stress Underneath an Ice Jam in the Lower Grasse River (Alcoa, 2004)

2004/2005 Grasse River Monitoring Work Plan (Alcoa, January 2005)

2004 Remedial Options Pilot Study Baseline Monitoring Summary Report (Alcoa, 2005)

Location Number	Ice Monitoring Location	Road Designation	Approximate Transect Number
1	Amvets Property	---	66
2	Haverstock Road	---	54
3	Massena Center	---	28
4	Route 131 Bridge	Route 131	22
5	Capping Pilot Study Area	---	16
6	Outfall 001	---	5
7	Alcoa Bridge	Alcoa Road	2
8	Parker Street Bridge	Route 37B	---
9	Main Street Bridge	Route 420	---
10	Route 37 Bridge	Route 37	---
11	Massena Rod and Gun Club	---	---
12	Louisville Bridge	Route 39	---
13	Chase Mills Bridge, USGS Gage	Route 36	---
14	Chamberlain Corners Bridge	Route 44	---
15	Madrid Bridge	Route 345	---
16	Bucks Road Bridge	Route 34	---
17	Canton Bridge	Route 68	---

Table 1
Grasse River, Massena New York
Ice Monitoring Locations



OTHER MONITORING LOCATIONS UPSTREAM OF LOUISVILLE BRIDGE, MONITORING LOCATION 12

No.	LOCATION	DISTANCE UPSTREAM*
13	CHASE MILLS BRIDGE, RT.36	5 ml
14	CHAMBERLAIN CORNERS BRIDGE, RT. 44	6.75 mi
15	MADRID BRIDGE, RT. 345	12 mi
16	BUCKS BRIDGE, RT. 34	15.75 mi
17	CANTON BRIDGE, RT. 68	25.75 mi

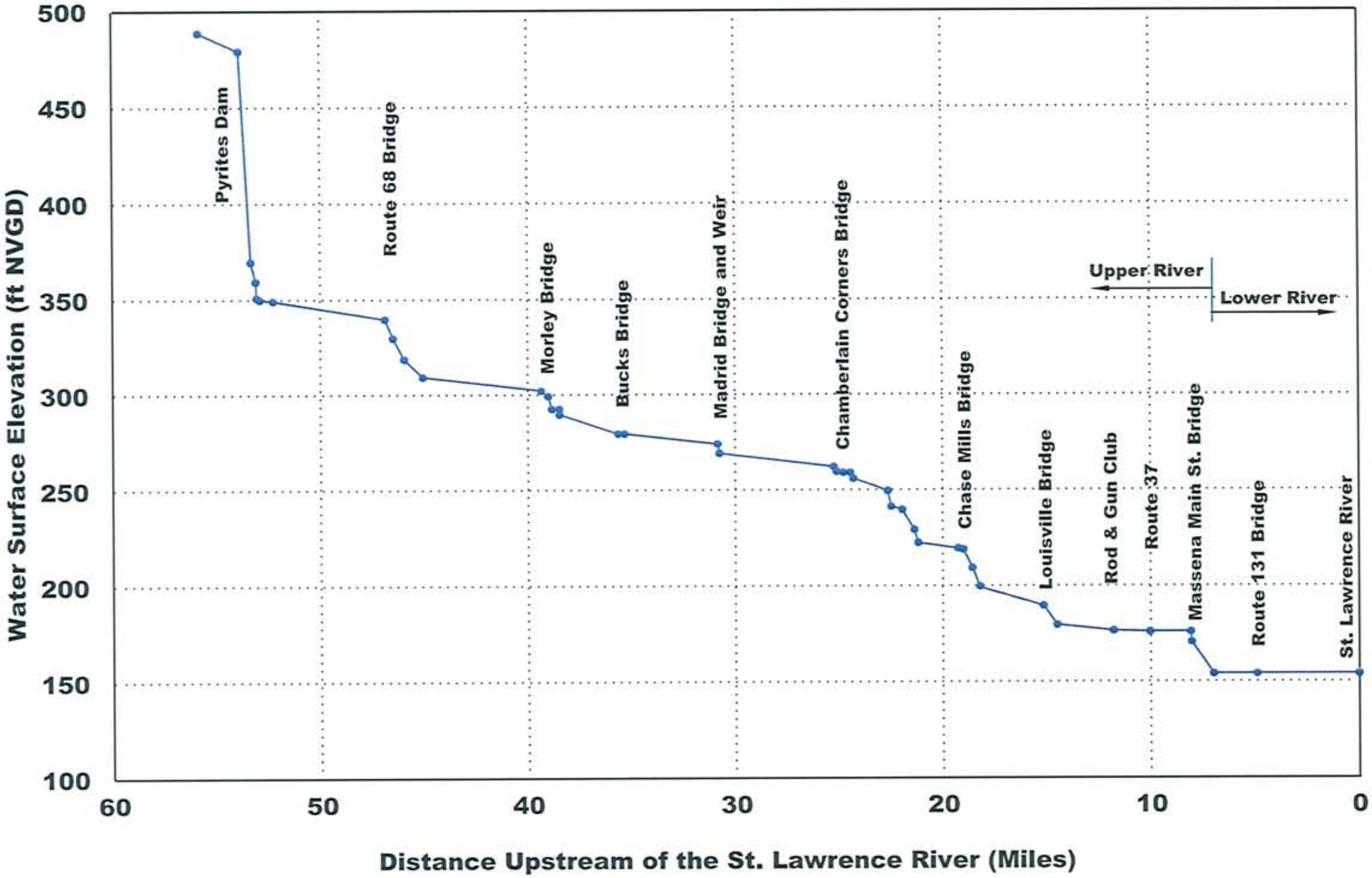
* ALL DISTANCES ARE REFERENCED FROM LOUISVILLE BRIDGE AND ARE APPROXIMATE.

GRASSE RIVER STUDY AREA
MASSENA, NEW YORK

2004/2005 GRASSE RIVER ICE MONITORING LOCATIONS

ALCOA

FIGURE 1



GRASSE RIVER STUDY AREA
MASSENA, NEW YORK

PROFILE OF GRASSE RIVER ICE MONITORING LOCATIONS

ALCOA

FIGURE
2

Note:

1. Water surface elevations obtained from USGS 7.5 minute series topographic quadrangles.

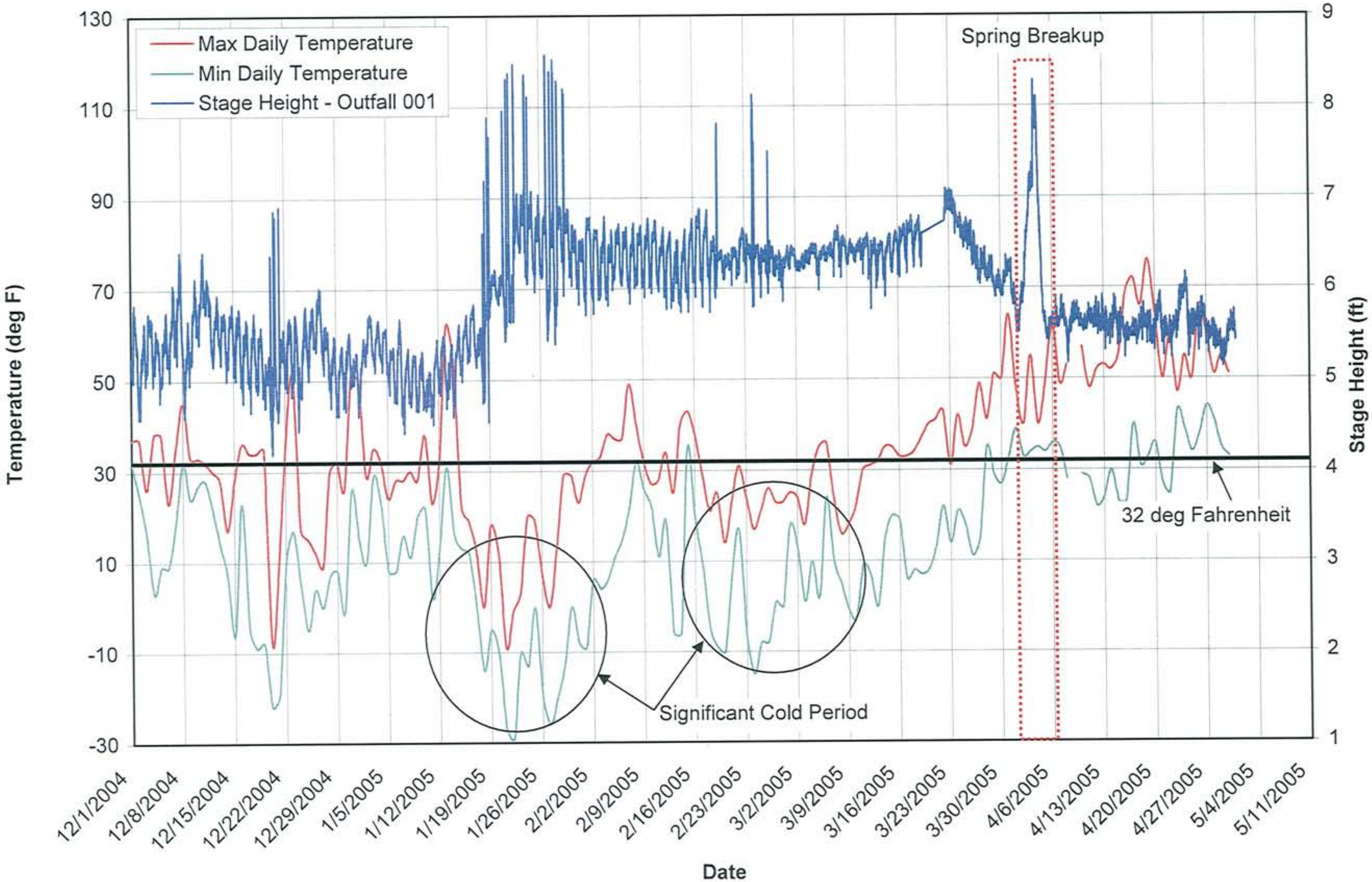


Figure 3
Air Temperature for Winter 2004/2005
Massena, New York

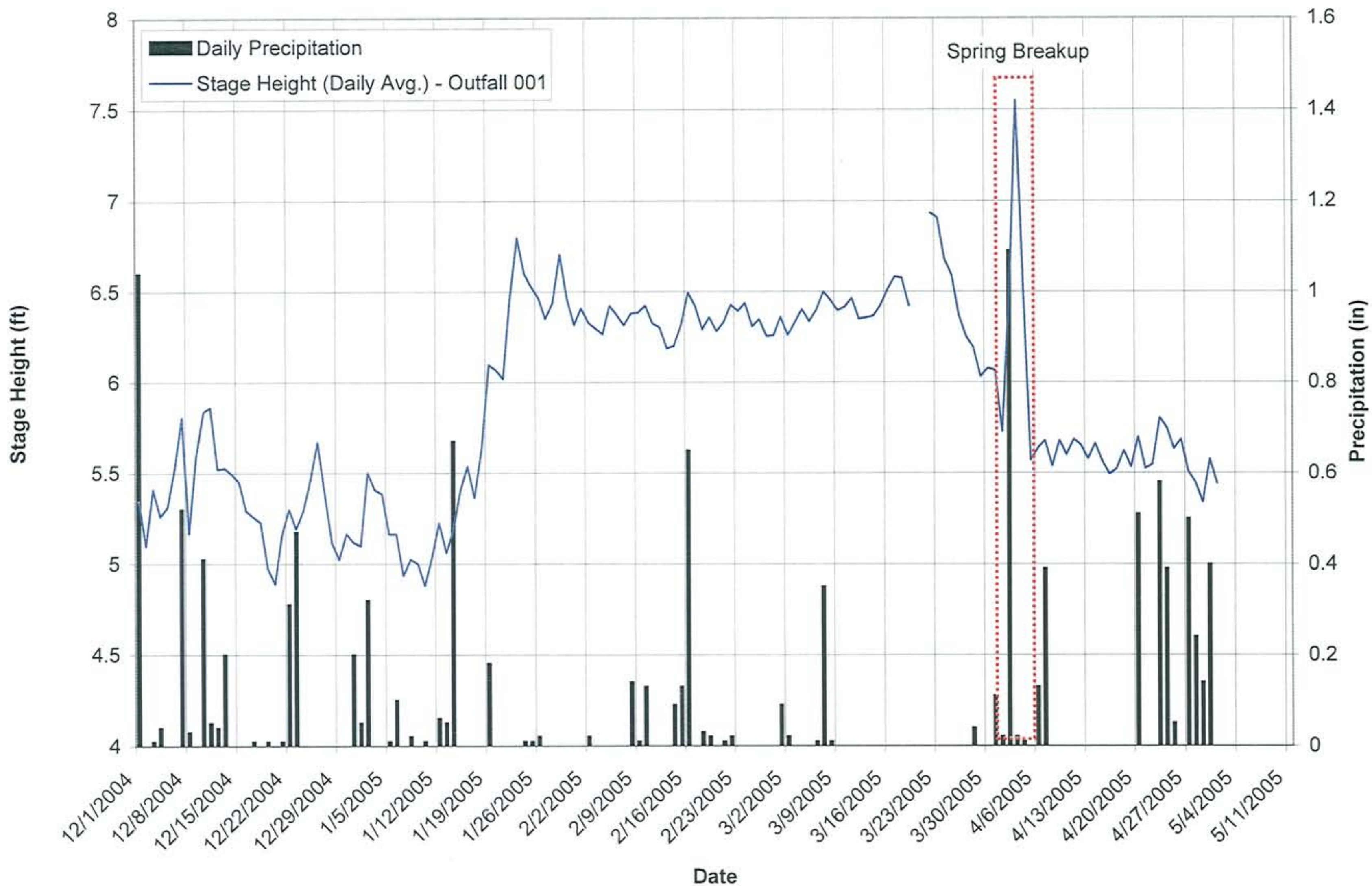


Figure 4
Precipitation Data for Winter 2004/2005
Massena, New York

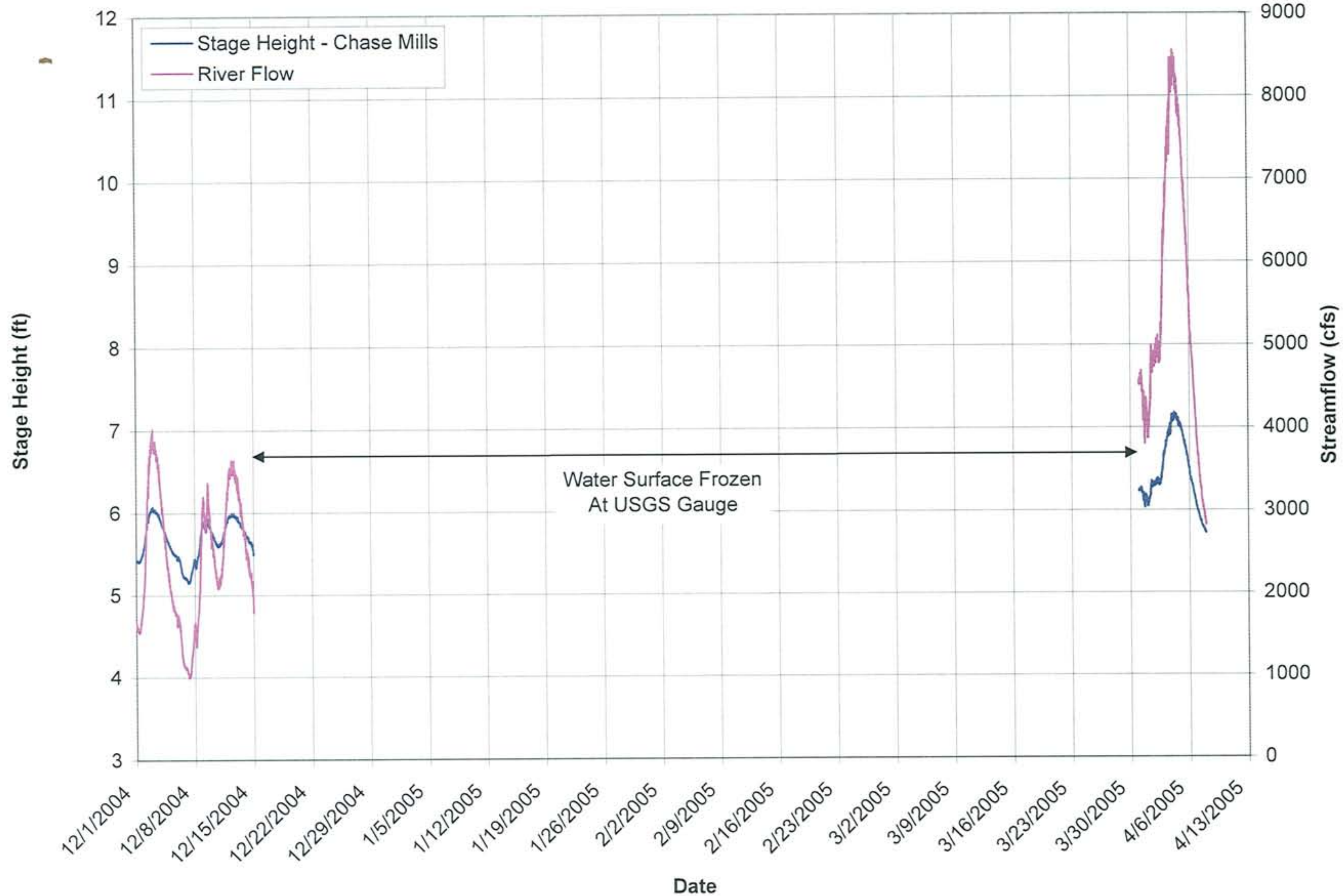


Figure 5
Grasse River Stage Height for Winter 2004/2005
Chase Mills, New York USGS Gauging Station

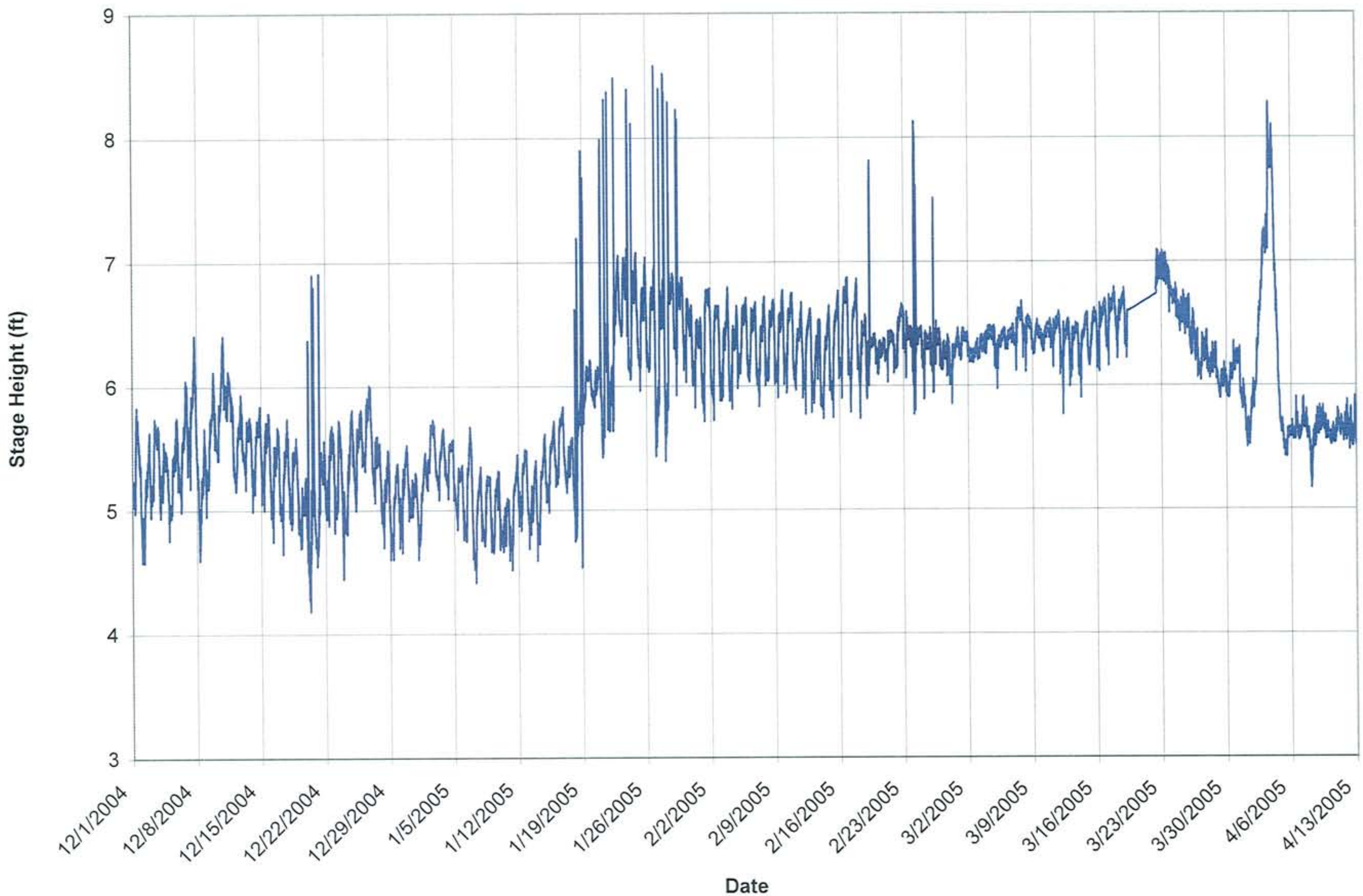
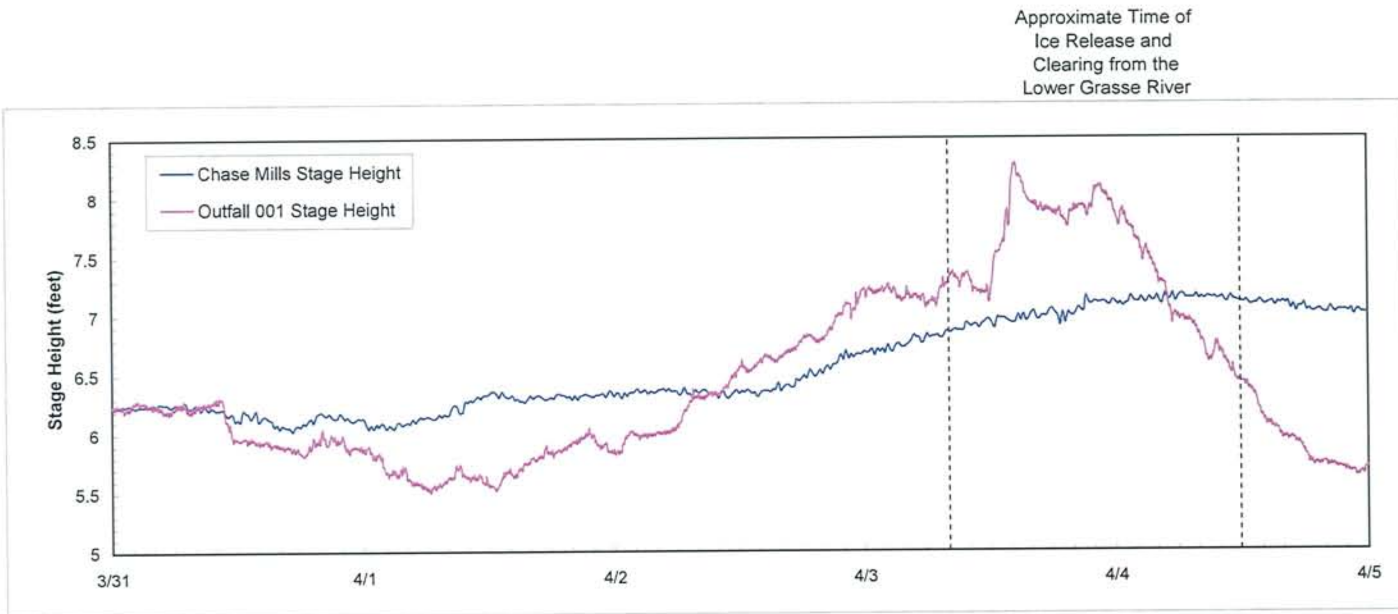
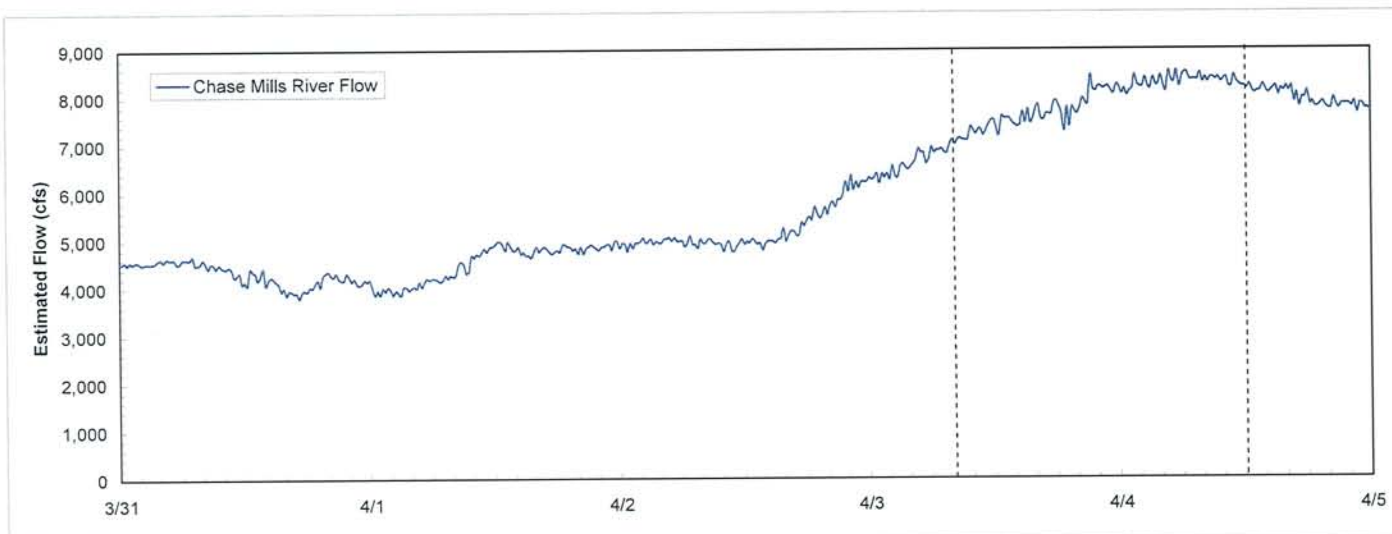


Figure 6
Grasse River Stage Height for Winter 2004/2005
Alcoa Outfall 001 Staff Gauge - Massena, New York





Notes:
- Real-time stage height and flow data was collected from the USGS website for the gaging station at Chase Mills, NY (#04265432)
- Real-time stage height data was collect from the staff gage at the Alcoa West Outfall 001 in Massena, NY.

Figure 7
Stage Height and Flow for the Spring 2005 Ice Breakup
Chase Mills USGS Gauge and Outfall 001 Staff Gauge

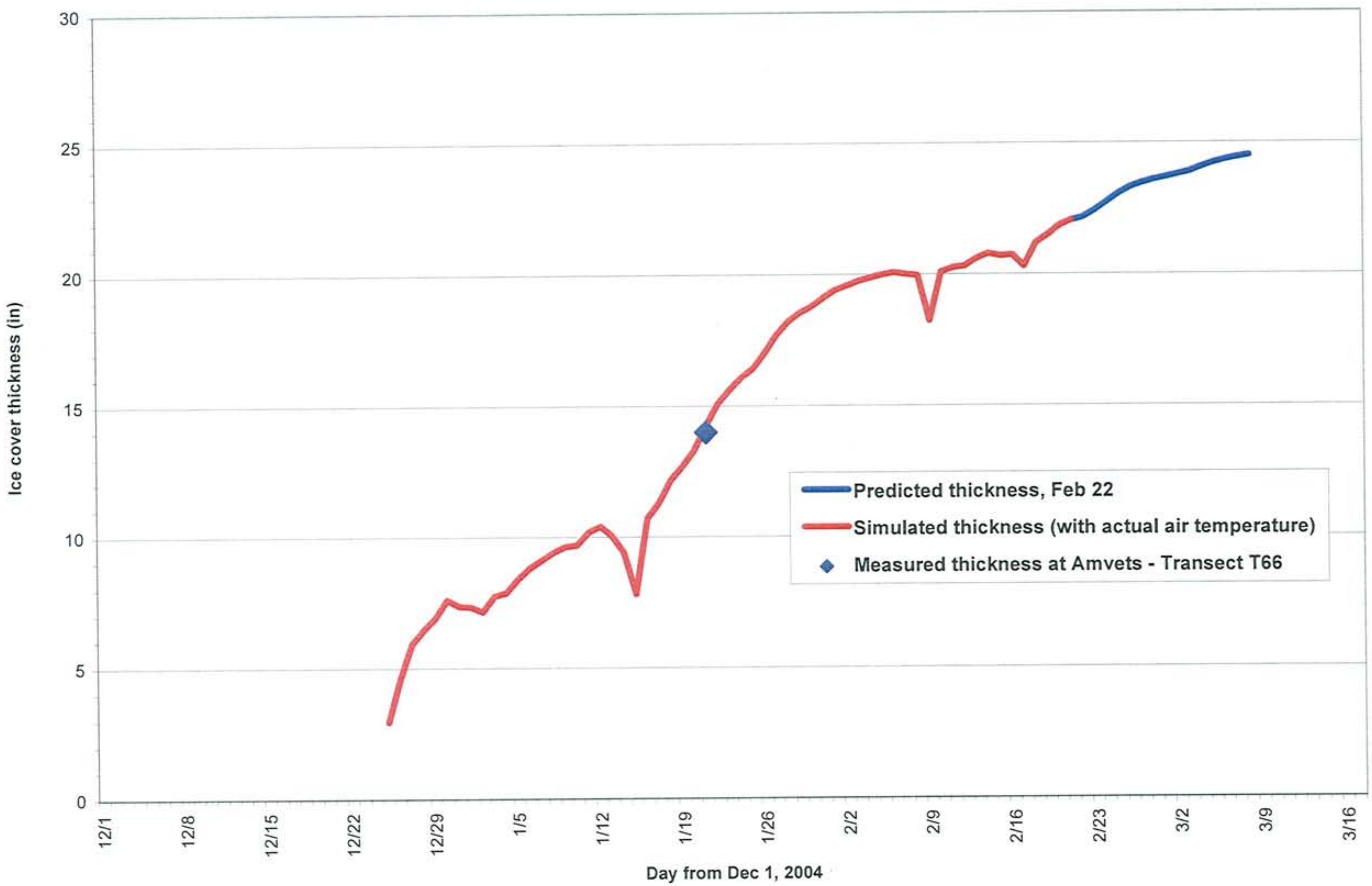
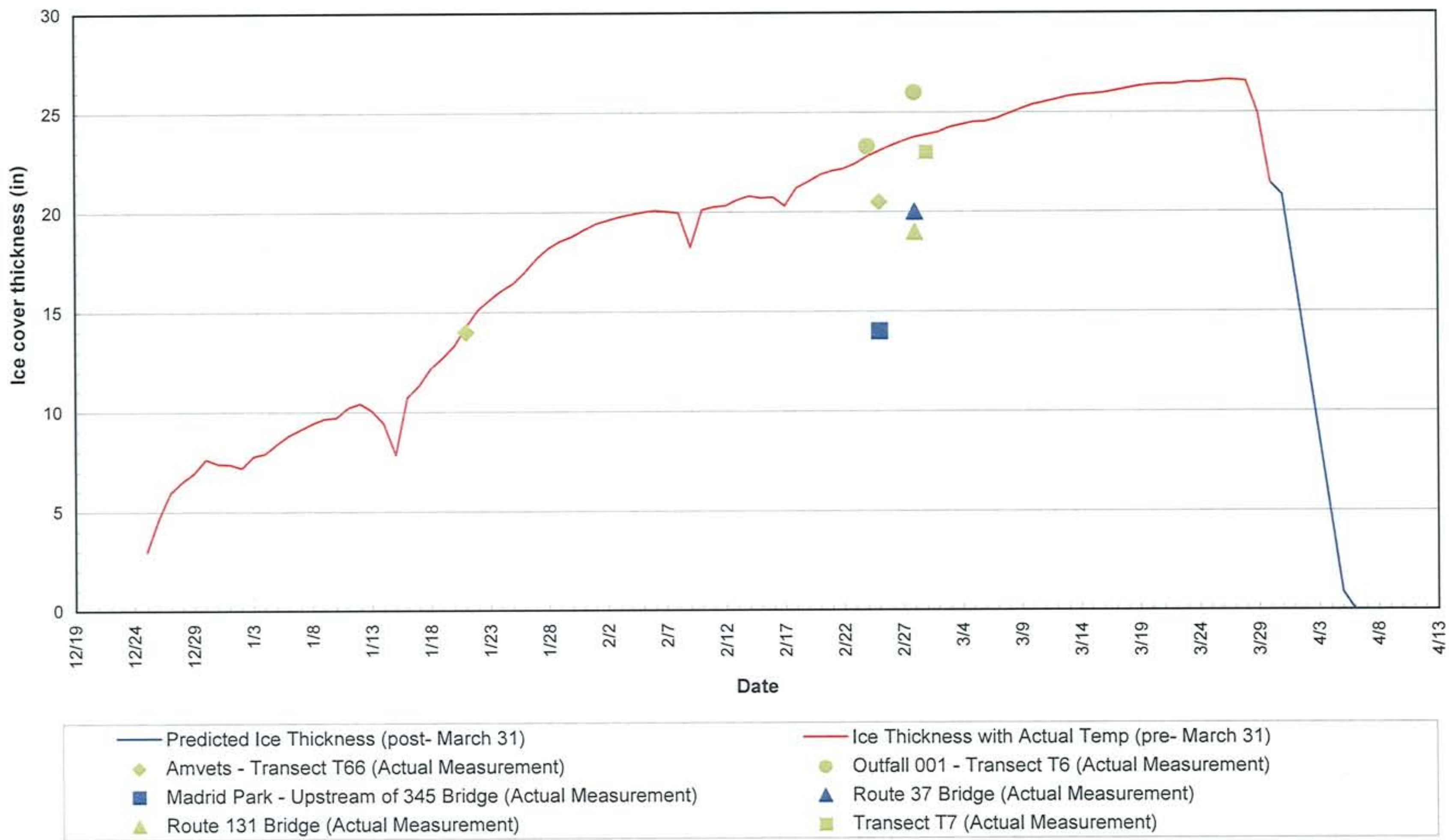


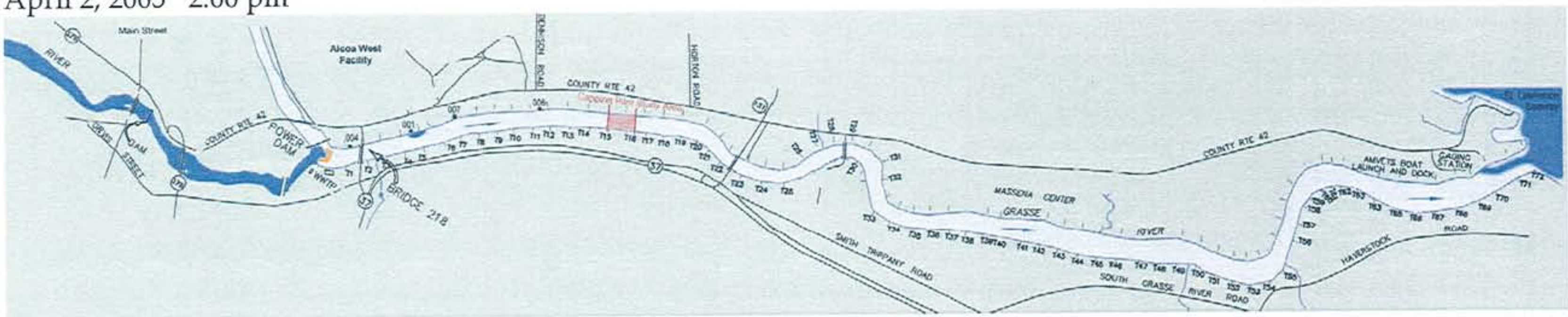
Figure 8
Grasse River
Simulated Ice Cover Thickness - February 22, 2005



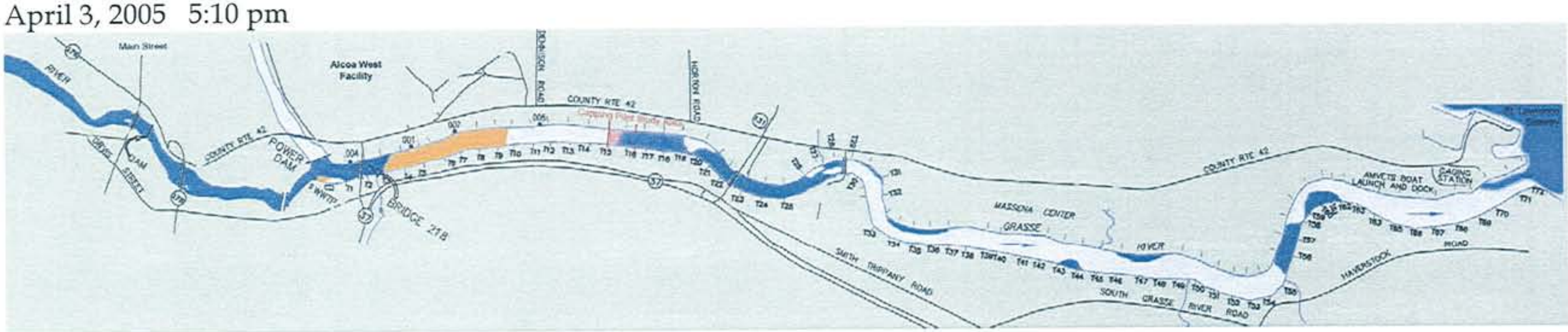
Notes:
Ice thickness predictions from Clarkson University (Potsdam, NY)
Ice thickness measurements by CDM (Massena, NY)

Figure 9
Grasse River
Simulated Ice Cover Thickness for Winter 2004/2005

April 2, 2005   2:00 pm



April 3, 2005   5:10 pm



April 4, 2005   6:45 am

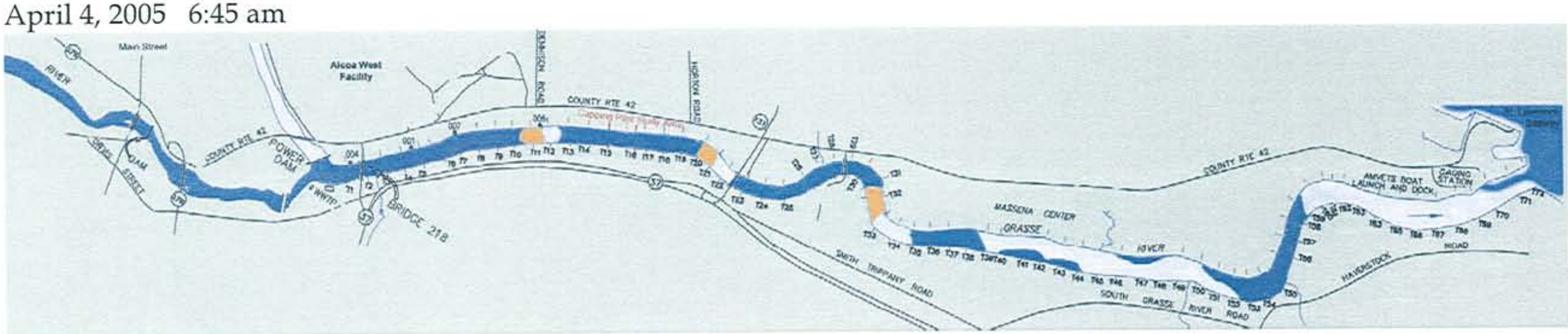
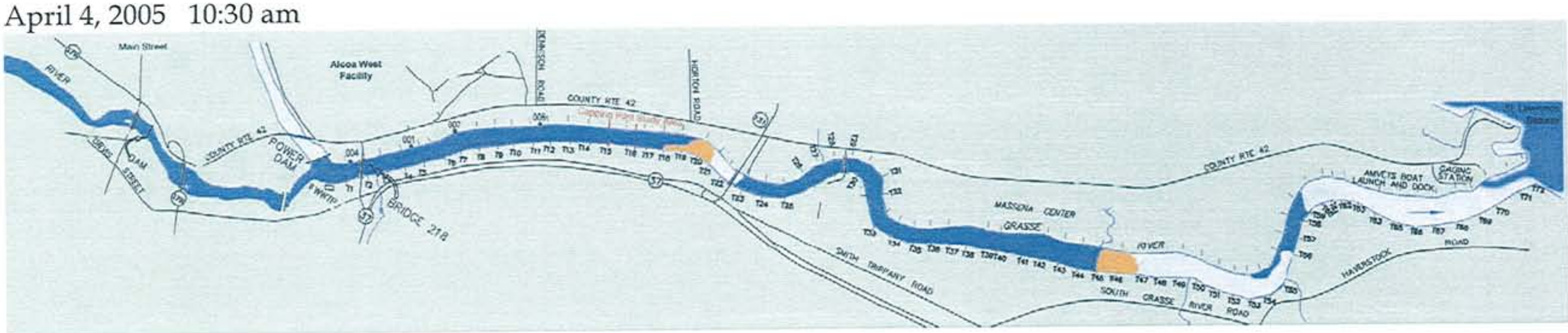


Figure 10
Lower Grasse River
Location of Ice Accumulation and Ice Cover

April 4, 2005 10:30 am



April 4, 2005 2:45 pm

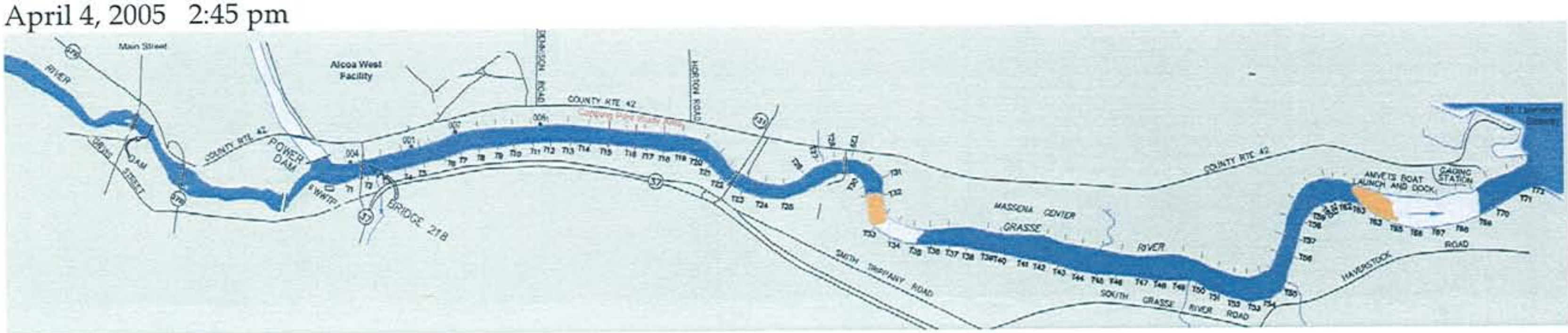


Figure Key

- Ice Accumulation
- Ice Cover
- Open Water

Figure 10
Lower Grasse River
Location of Ice Accumulation and Ice Cover

Figure 11a: From Outfall 001 looking upstream towards the Alcoa Bridge

Figure 11b: High concentration of ice flow upstream of the Alcoa Bridge

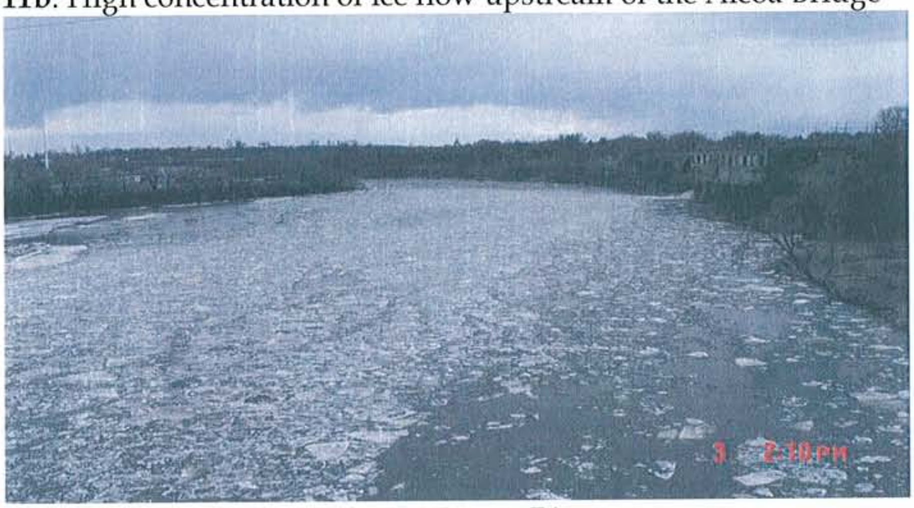


Figure 11c: Ice and debris in the lower Grasse River

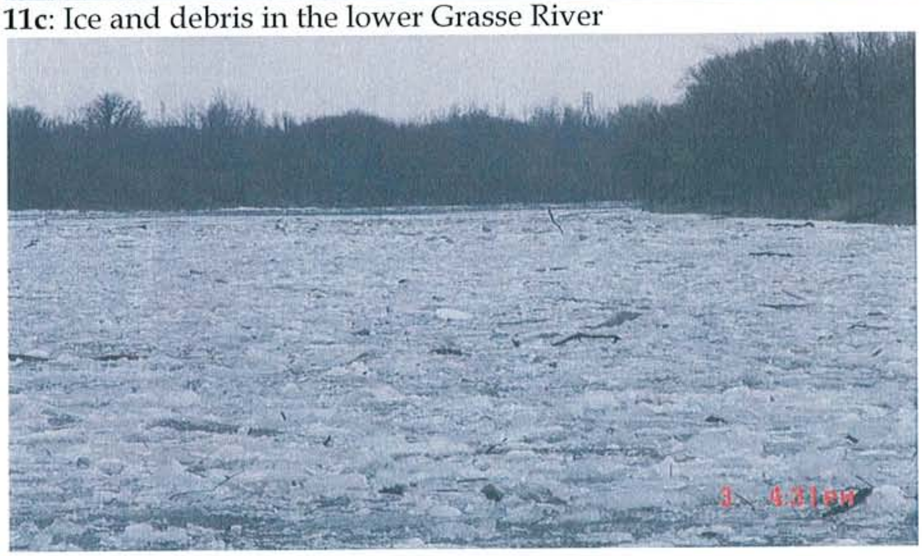
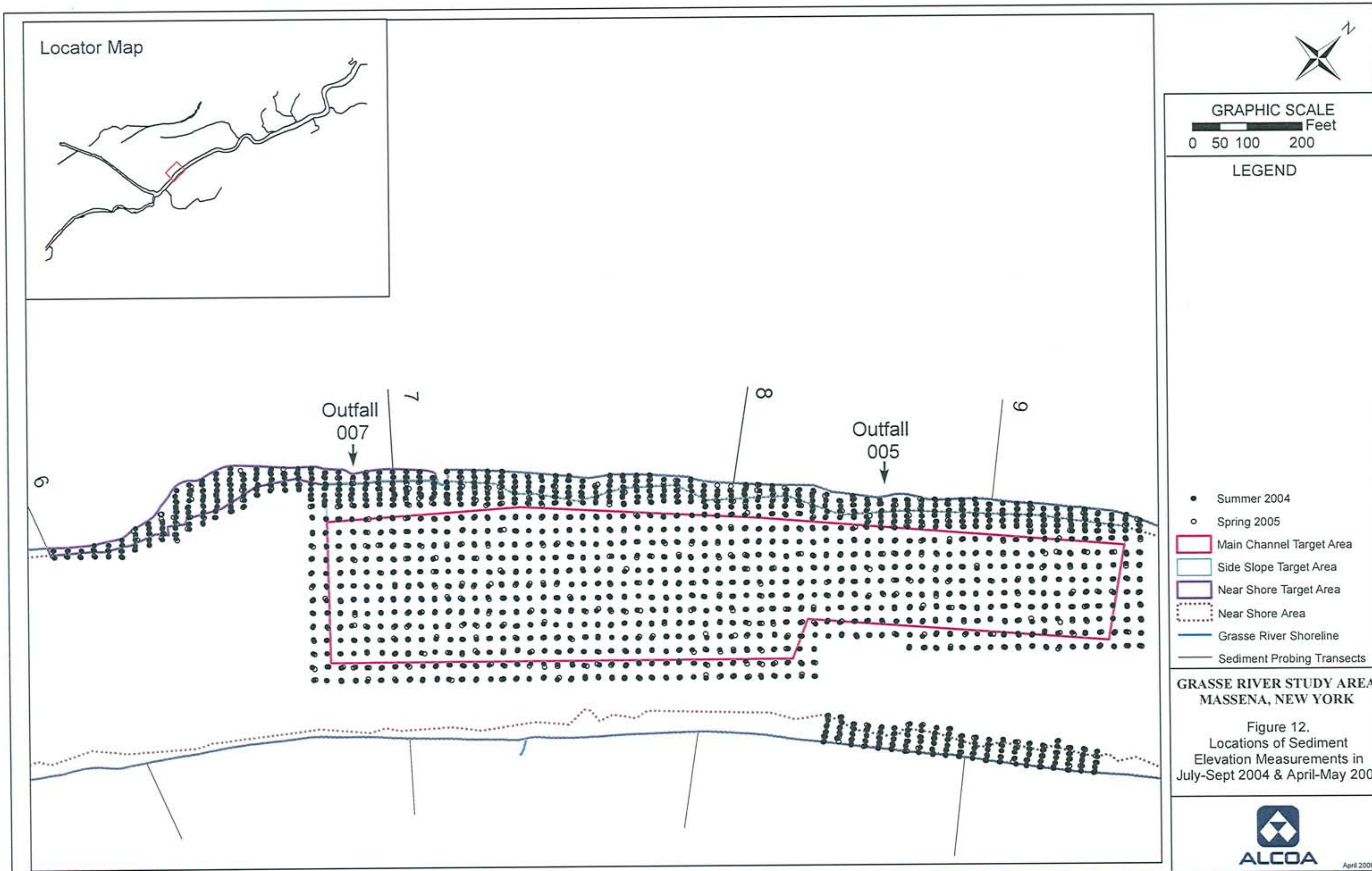


Figure 11
Lower Grasse River
Photographs During Breakup – April 3, 2005

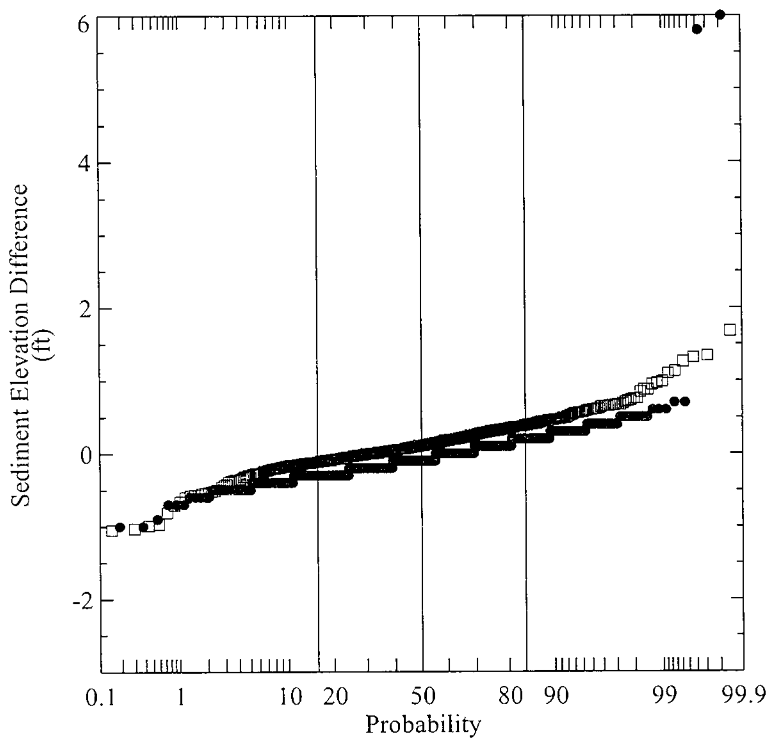


ARC:\\ARCID_drive\ALCgra\Analysis\ROPS\GIS\sediment\pre\probing\rops_probing_MC2005arc_060329.mxd

GRASSE RIVER STUDY AREA
MASSENA, NEW YORK

Figure 13.
Sediment Elevation Differences in the Main Channel from 2004 to 2005 Based on ROPS Baseline Monitoring Data

ARC:\\ARCID_drive\ALCgra\Analysis\ROPS\GIS\sediment\pre\probing\rops_probing_MC2005arc_060329.mxd



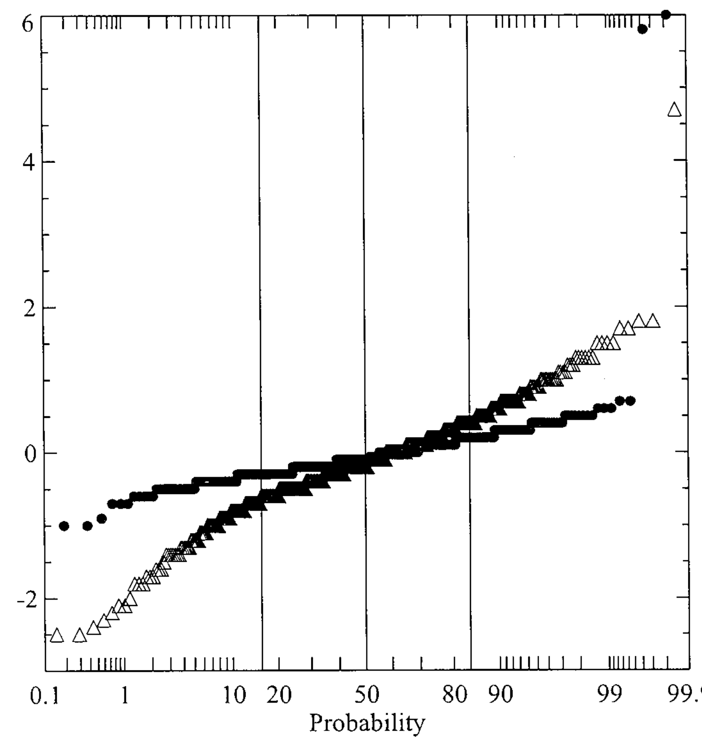


Figure 14. Comparison of Sediment Elevation Differences in the Main Channel of the ROPS Area

• 2004: R1 vs R2
□ 2003 MB vs 2004
△ 2004 vs 2005

2004 and 2005 measurements collected via manual probing.
Elevations based on USLS 1935 Datum.
Data tables: sed_probe_ROPS

ARC - D:\ALCgra\Analysis\ROPS\IDL\sediment\probing\bathymetry\ROPS_sedelev_MBvsProbing.pro
Fri Apr 07 15:43:50 2006

Appendix A

Disk 1

- **Photo Library - Winter 2004/2005 River Ice Monitoring**

- **Monthly Stage Height Records for Gauge at Alcoa Outfall 001 – 2004 & 2005**

(Note: Data not available for January, October, November 2004)

Disk 2

Video Documentation of Lower Grasse River Ice Breakup - April 3 & 4, 2005

(Note: Provided in ***Technical Memorandum – Grasse River Project 2004/2005 River Ice Monitoring Documentation Summary- Issued December 21, 2005*****)**

Appendix B
Grasse River Ice Cover Forecasting, Winter 2004/2005

Grasse River Ice Cover Forecasting, Winter 2004 - 2005

Report Submitted to

Camp Dresser & McKee
88 Parker Avenue
Massena, NY 13662

By

Nimal C. Jayasundara and Hung Tao Shen

Department of Civil and Environmental Engineering
Clarkson University, Potsdam, NY 13699-5710

May 2005

Table of content

List of Figures

List of Tables

1.0 Introduction

Lower Grasse River, Massena, NY 2004-05 winter ice cover evolution was forecasted using a unified degree day method (Shen and Yapa 1985). This method was successfully applied for ice jam hindcasting in the lower Grasse River (Shen et al. 2003). According to the hindcasting analysis, the ice cover in the Grasse River breaks up when the discharge increase from the maximum winter freezing period flow exceeds 3,500 cfs. An ice jam in the lower Grasse River is possible if the upstream breakup ice cover thickness is more than 15 inches. Forecasted air temperature for Massena was obtained from http://www.accuweather.com .

Synthesized flow data was used in the Grasse River hindcasting analysis (Shen et al. 2003). However, flow data for the 2005 winter was not available due to the presence of ice on the river. The USGS gauging station at Chase Mills measures the flow data only during open water conditions. Since the flow data was unavailable for the ice covered period, ice breakup was predicted based on the forecasted precipitation and air temperature data. It is assumed that if there is rainfall with warm air temperature to cause a significant increase in river flow, the cover is subject to breakup. A breakup jam is possible if the breakup ice cover thickness is more than 15 inches.

This report summarizes the forecasted results of growth and decay of the ice cover thickness and the forecast of ice jam potential in the lower Grasse River for the winter 2004/2005.

2.0 Cover thickness and decay forecasting

Figure 1 shows the simulated ice cover thickness, t_i, with 15-day forecasted air temperature on different days during the winter. The simulated thickness with normal air temperature and with real air temperature, as well as observed cover thickness data is also included. Cover thickness prediction was started on January 27, 2005 and continued through March 31, 2005. The different color line segments along the cover thickness line are the 15-day predicted thickness values on the days from January 27 to March 30. The data points (geometric shapes) represent the measured solid ice thickness provided by CDM and/or BB&L. The vertical color line segments above the data point represent the measured frozen frazil thickness (thick purple line) and snow cover thickness (dark green line). For purposes of comparison, the combined thickness of the solid ice and frozen frazil can be regarded as the total ice cover thickness. Figure 2 shows the Massena air temperature and precipitation data. Figure 3 shows the same thickness data as Figure 1 but without air temperature data. The observed thickness on January 21 at Amvets (T66), February 24 at T6 and March 1 at T7 compare well with predicted thicknesses.

The simulated cover thickness reached a maximum thickness of 26.6 inches by March 27 before it started to decay. If the cover was not mechanically broken up, it would be expected to melt-out by April 6. However, with the rainfall and warm temperature forecasted for the week following March 30, it was predicted that the cover will breakup mechanically, but a jam was not likely to occur due to the rapid decay of ice cover forecasted. Aerial observation on March 31 showed that there were signs of cover breakup initiation in upper Grasse River (Tuthill 2005). March 31 and April 1 forecasted cover thickness were 20.8 inches and 16.8 inches, respectively, and there was a total 0.13 inches of rainfall on these two days (Table 1). The breakup in the lower Grasse River was observed on April 3 by CDM Massena office. The forecasted thickness for April 3 was 8.8 inches. A mild jam was observed due to the breakup in the upper Grasse River cover preceeding the breakup in the lower Grasse River.

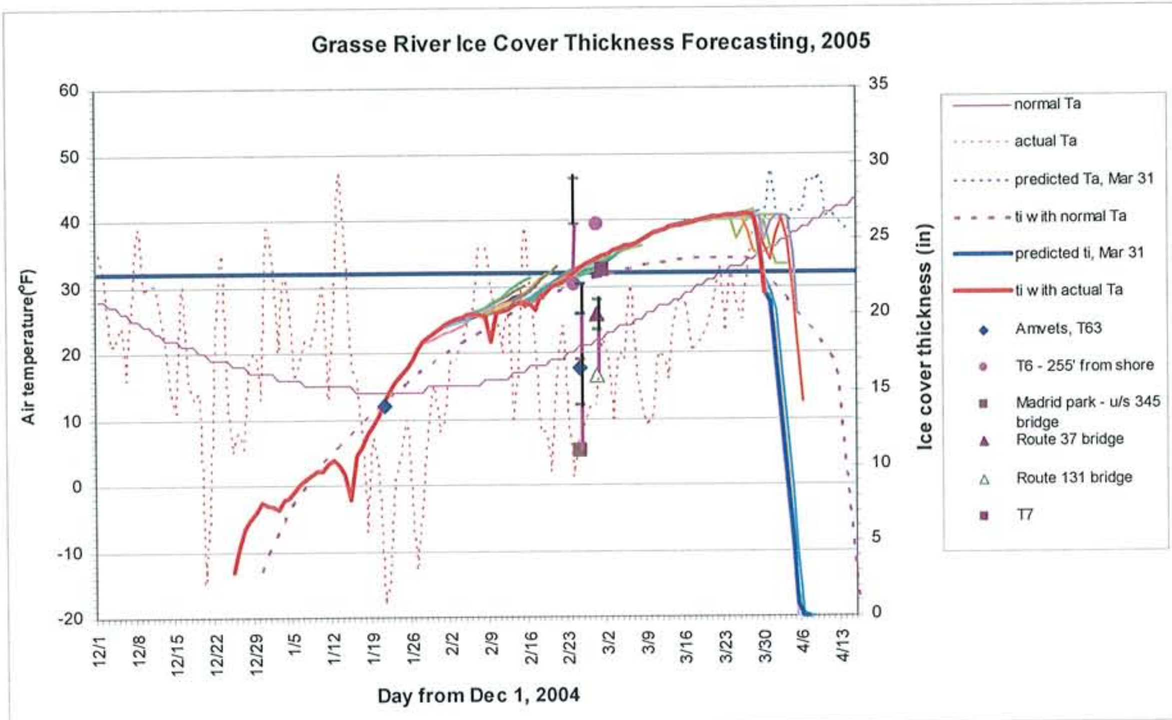


Figure 1 Grasse River forecasted and observed ice cover thickness with air temperature, winter 2004-05

Note: Solid yellow, green, orange, purple and light blue lines that run parallel to the simulated ice cover thickness (red) and predicted ice cover thickness on March 31 (dark blue), are predicted thickness values based on forecasts prior to March 31.

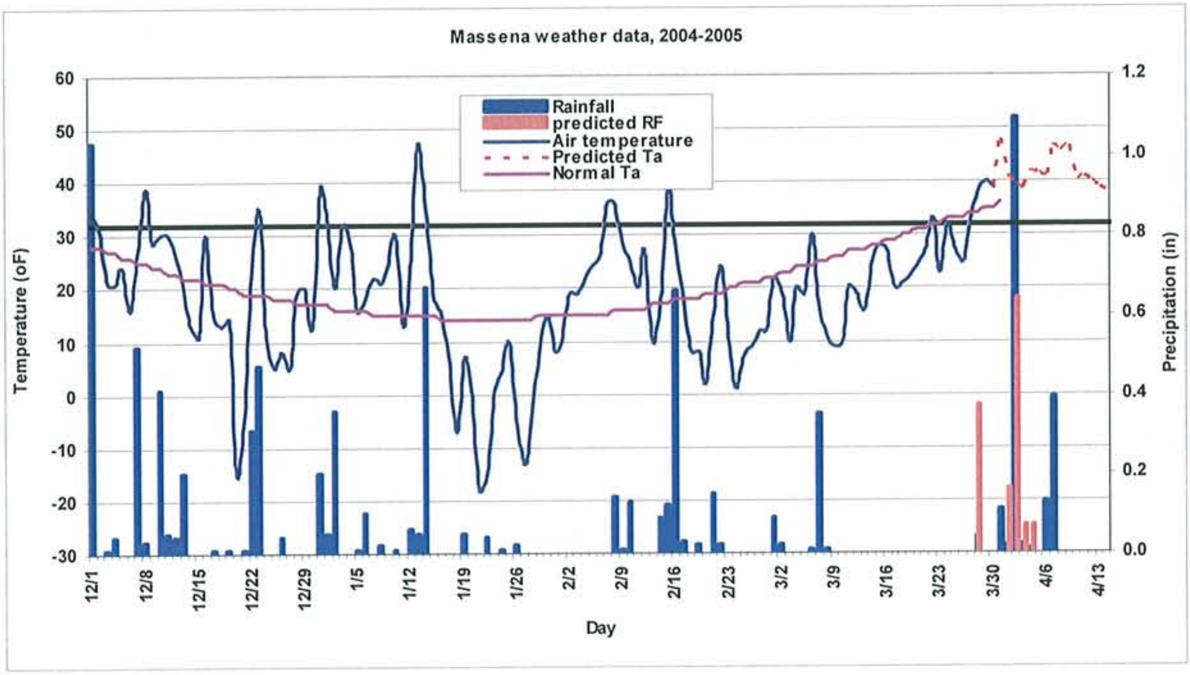


Figure 2 Massena air temperature and precipitation, winter 2004-2005

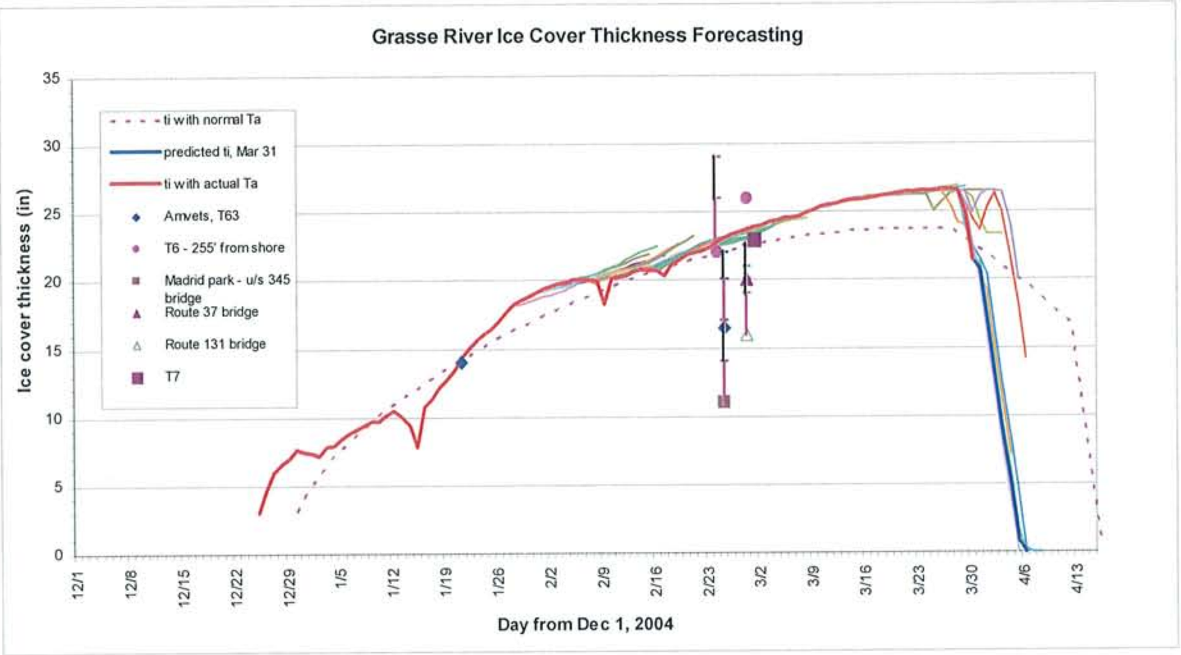


Figure 3 Grasse River forecasted and observed ice cover thickness, winter 2004-2005

Note: Solid yellow, green, orange, purple and light blue lines that run parallel to the simulated ice cover thickness (red) and predicted ice cover thickness on March 31 (dark blue), are predicted thickness values based on forecasts prior to March 31.

Table 1 Air temperature and rainfall forecast

Date	Forecasted on March 31, 2005			Actual	
	Cover thickness (in)	Rainfall (in)	Air temperature (^oF)	Rainfall (in)	Air temperature (^oF)
March 31	20.8	0	47.5	0.11	49
April 1	16.8	0.16	41.0	0.02	44
April 2	12.8	0.64	39.5	1.09	37
April 3	8.8	0.07	38.5	0.02	45
April 4	4.8	0.07	41.5	0.01	38
April 5	0.8	0	41.5	0	42
April 6	0	0	41.0	0.13	49

3.0 References

Fisheries and Oceans Canada, Marine Environmental Data Services, http://www.meds-sdmm.dfo-mpo.gc.ca/meds/databases/TWL/TWL_e.htm

Massena weather data. http://www.accuweather.com

Shen, H.T. and Yapa, P.D. 1985. A unified degree-day method for river ice cover thickness simulation. *Canadian Journal of Civil Engineering*. 12, 54-62.

Shen, H. T., Jayasundara, N.C. Tuthill, A. (2003). Occurrence of Breakup ice jams in Lower Grasse River. Report No. 03-18. Department of Civil and Environmental Engineering. Potsdam, NY 13699-5710

Tuthill, A., Pre-breakup Ice Conditions on Grasse River March 31, 2005, April 1, 2005 Memo submitted to CDM.

U.S. Geological Survey, http://waterdata.usgs.gov/nwis/uv/?site_no=04265432

Appendix A Cover thickness calculation program

```
      program DegreeDay

! Program to calculate river ice thickness evolution and decay
! using freezing degree day (FDD) method
! Nimal C. Jayasundara and H.T. Shen
! Department of Civil and Environmental Engineering
! Clarkson University
! Potsdam, NY 13699-5710
! July 15 2003
! input - air temperature data in CFDDin.dat file
! input - parameters in param.dat file
! output - CFDDout.dat file

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

      parameter(nd = 300)
      real ta(nd), fdd(nd), cfdd(nd), icethick(nd),alpha(nd), Ta2(nd)
      real icet0, hmax, inithi
      real alpha0,alpha1, delhr, beta, theta, bb, mm,hh, key, ini_CFDD
      integer no_days, day(nd), ini_day, imax

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

      open (unit = 2, file = 'input\'//'param.dat')
      open (unit = 3, file = 'input\' //'CFDDin.dat')
      open (unit = 7, file = 'output\' //'CFDDout.dat')

!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
      read(2,*)
      read(2,*) key! key = 1 use ini_day = 2 use ini_CFDD
      read(2,*) ini_day   ! cover initiation day
      read(2,*) ini_CFDD  ! CFDD for cover initiation
      read(2,*) inithi    ! initial cover thickness
      read(2,*) alpha0
      read(2,*) mm
      read(2,*) beta
      read(2,*) theta
      read(2,*) alpha1
      read(2,*) delhr
      read(2,*) bb
      read(2,*) Tb

      read(3,*)
      read(3,*) no_days
      read(3,*)

      j=1
      hmax = 0.0

      write(7,140) 'day','alpha','FDD','CFDD','i_thick(in)'
      write(*,140) 'day','alpha','FDD','CFDD','i_thick(in)'


      do 50 i=1, no_days

             read(3,*) day(i), ta(i)

             fdd(i) = 32 - ta(i)
```

```
            if (i .eq. 1) then
                  cfdd(i) = fdd(i)
            else if (i .gt. 1) then
                  cfdd(i) = cfdd(i-1) + fdd(i)
            end if


            if (key .eq. 1 .and. i .lt. ini_day) goto 50   !wait for cover initiation
            if (key .eq. 2 .and. cfdd(i) .lt. ini_CFDD) goto 50 !wait for cover
initiation

            if (j .eq. ini_day) goto 20
            if (key .eq. 2 ) then      ! assign initial day for initial CFDD option
                  ini_day = i
                  j =ini_day
            end if
20          continue


            Ta2(i) = ( fdd(i-1)+fdd(i-2) )/2.0

            if (Ta2(i) .ge. Tb) then
                  alpha(i) = alpha0
            else if ( Ta2(i) .lt. Tb) then
                  alpha(i) = alpha0+ (Ta2(i)-Tb)* mm
                  if (alpha(i) .lt. 0.0) alpha(i) = 0.0
            end if

      if (i_det .gt. 1) goto 25  ! cover decay


            icethick(i)= sqrt(inithi**2.0 + alpha(i)*(cfdd(i)-cfdd(ini_day)))
     &                        - beta*(day(i)**theta)

            if (icethick(i) .ge. hmax) then
                  hmax = icethick(i)
                  imax = i
            end if

            hh = hmax-delhr

            if (icethick(i) .le. hh) then
                  i_det = i
                  goto 25 !then ! deterioration
            else if (icethick(i) .gt. hh) then
                        write(7,150) day(i),alpha(i),fdd(i),cfdd(i),icethick(i)
                        write(*,150) day(i),alpha(i),fdd(i),cfdd(i),icethick(i)
                  goto 50
            end if

      !     end if

25    continue
            if (alpha(i) .ge. alpha1) then

              icethick(i)= sqrt(inithi**2.0 + alpha(i)*(cfdd(i)-cfdd(ini_day)))
                        if (icethick(i) .gt. icethick(i-1)) then
                              icethick(i) = icethick(i-1)
                        end if

            else if (alpha(i) .lt. alpha1)  then
```

```
                    ii = i
                    !      do j= ii, no_days
                                  icethick(i) = icethick(i-1)-bb
                                  if(icethick(i) .lt. 0.0) icethick(i) = 0.0

                    if (icethick(i) .gt. icethick(i-1)) icethick(i) = icethick(i-1)
!then

c                          end if

                           write(7,150) day(i),alpha(i),fdd(i),cfdd(i),icethick(i)
                           write(*,150) day(i),alpha(i),fdd(i),cfdd(i),icethick(i)

                           if(icethick(i) .eq. 0.0) then
                                  write(*,*) 'cover melt-out'
                                  stop
                           end if

                           goto 50
              end if

50     continue
140    format(a4,4a12)
150    format(i4,4f12.3)

       pause
       end
```

Appendix B Input - Program coefficients and parameters

```
parameters- Station Massena E2
1      1 use cover start date, 2 use initial CFDD
25     ice cover starting day
300    initial CFDD, CFDD for cover initiation
3.0    initial cover thickness (inch)
0.52   alpha0
0.03   m
0.0    beta
1.0    theta
0.4    alpha1
7.0    delta hR
4.0    b
-1.0   Tb
```

Description of parameters file

Line 1: Option to select cover simulation starting date

> Air temperature data is given the CFDDin.dat file, from the beginning of the winter. But the user has to give a cover initiation point. This can be given as a day number from beginning of the winter or initial Cumulative freezing Degree Day (CFDD).
>
> 1: cover initiate on the day given in next line
> 2: cover initiate when the CFDD reach to the value in line 3

Line 2: Cover initiation day
Line 3: Cover initiation CFDD
Line 4: initial cover thickness
Line 5 – 12 model parameters

Appendix C Sample input – 2004-2005

```
"Massena, Days from 1 December 12/1/05
134     no of days
Day     Ta
1       35
2       31
3       21
4       21
5       24
6       16
7       27
8       39
9       29
10      30

:
:
:
:
:
128     46.5
129     45.5
130     29.5
131     31
132     32.5
133     35.5
134     37
```

Description of air temperature file

Line 1: comments
Line 2: number of days (lines) in the data file
Line 3: comments
Line 4 to number of days
    Column 1 day number
    Column 2 air temperature in ^{o}F

Appendix D Sample output – 2004-2005

day	alpha	FDD	CFDD	i_thick(in)
25	0.520	27.000	300.000	3.000
26	0.520	24.000	324.000	4.635
27	0.520	27.000	351.000	5.960
28	0.520	13.000	364.000	6.502
29	0.520	12.000	376.000	6.966
30	0.520	19.000	395.000	7.642
31	0.520	-7.000	388.000	7.400
32	0.520	-1.000	387.000	7.365
33	0.430	12.000	399.000	7.181
34	0.520	0.000	399.000	7.777
35	0.520	4.000	403.000	7.909
36	0.520	16.000	419.000	8.419
37	0.520	14.000	433.000	8.841
38	0.520	10.000	443.000	9.130
39	0.520	11.000	454.000	9.438
40	0.520	8.000	462.000	9.656
41	0.520	2.000	464.000	9.710
42	0.520	19.000	483.000	10.206
43	0.520	9.000	492.000	10.433
44	0.520	-15.000	477.000	10.052
45	0.460	-3.000	474.000	9.436
:				
:				
:				
:				
112	0.520	-1.000	1623.000	26.400
113	0.520	9.000	1632.000	26.488
114	0.520	0.000	1632.000	26.488
115	0.520	5.000	1637.000	26.538
116	0.520	7.000	1644.000	26.606
117	0.520	0.000	1644.000	26.606
118	0.520	-6.000	1638.000	26.547
119	0.460	-8.000	1630.000	24.916
120	0.340	-7.000	1623.000	21.420
121	0.325	-17.000	1606.000	20.819
122	0.190	-12.000	1594.000	16.819
123	0.115	-5.000	1589.000	12.819
124	0.295	-15.000	1574.000	8.819
125	0.250	-9.500	1564.500	4.819
126	0.182	-9.000	1555.500	0.819
127	0.272	-9.000	1546.500	0.000

Description of output file

Line 1: comments
Column 1: Day number from cover initiation day
Column 2: parameter alpha (cover growth and decay parameter)
Column 3: Freezing Degree Day (^{o}F /day)
Column 4: Cumulative Freezing Degree Day from the beginning of winter (^{o}F /day)
Column 5: Cover thickness (in)

Appendix C
April 1, 2005 Memo and Aerial Photos

MEMO FOR RECORD
SUBJECT: Pre-breakup Ice Conditions on Grasse River, March 31, 2005
Date: April 1, 2005

Andy Tuthill inspected Grasse River ice conditions by airplane on the on the afternoon of March 31, 2005. The inspection followed two-and-a-half weeks of gradual thaw with one moderate rain event on March 30. During this period, daytime air temperatures typically reached the 40's and dropped below freezing at night. Significant rain is forecast for the weekend April 2-3, which will probably cause breakup on the Grasse River. The purpose of the March 31 recon flight was to document pre-breakup ice conditions. From the recon, it appears that much of the ice upstream of Massena has melted in place. The sheet ice sections on the upper river are dark-colored and sun-weakened, and it is unlikely that sufficient ice volume remains to supply a major jam on the lower river. Figs. 1 and 2 show the spatial extent of the ice covers.

The St. Lawrence is completely open below the Moses Saunders Power Dam and Snell Lock (Fig. 3). The lower Grasse River is covered in 6 miles of dark-colored, sun-decayed sheet ice from the mouth to about the near the old Power Dam where a small accumulation of floes could be seen (Figs. 4, 5 & 6). The river was open upstream through the Massena Rapids to a location about 1 mile below the Route 37 Bridge (Fig. 7). From here a 6-mile-long ice cover extended upstream to the foot of the Louisville Rapids (Figs. 8 & 9). Similar to the lower river ice, this ice was dark-colored and sun-decayed. A small accumulation of floes had piled up against the leading edge of the sheet ice at the foot of the rapids (Fig. 9). A third ice cover extended for about 2 miles above the Louisville Bridge. From here to the base of the Chase Mills Rapids, the river was about half ice covered and half open. A 3000-ft-long ice cover remained upstream of the Chase Mills railroad bridge (Fig. 10), above which the river was open to beyond Chamberlain Corners (Fig. 11). Other than a few rotted sheet ice sections, the river was predominantly open up to Madrid. Above Madrid a 2-mile-long sheet ice section (Fig. 12) gave way to alternating open (~70%) and ice covered sections (~30%) up beyond Bucks Bridge to Morley (Fig. 13). A 3-mile-long stretch of decayed sheet ice filled the broad bend upstream of Morely, ending about 1 mile below Canton (Fig 14). Above Canton (Fig. 15) the river was alternately open and sheet ice covered to the hydro dam at Pyrites (Fig 16).

Respectfully Submitted,

Andrew M. Tuthill, P. E.
Ice Engineering Group
Remote Sensing/ GIS Branch
US Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Rd.
Hanover, NH 03755

603-646-4225 phone 4477 fax

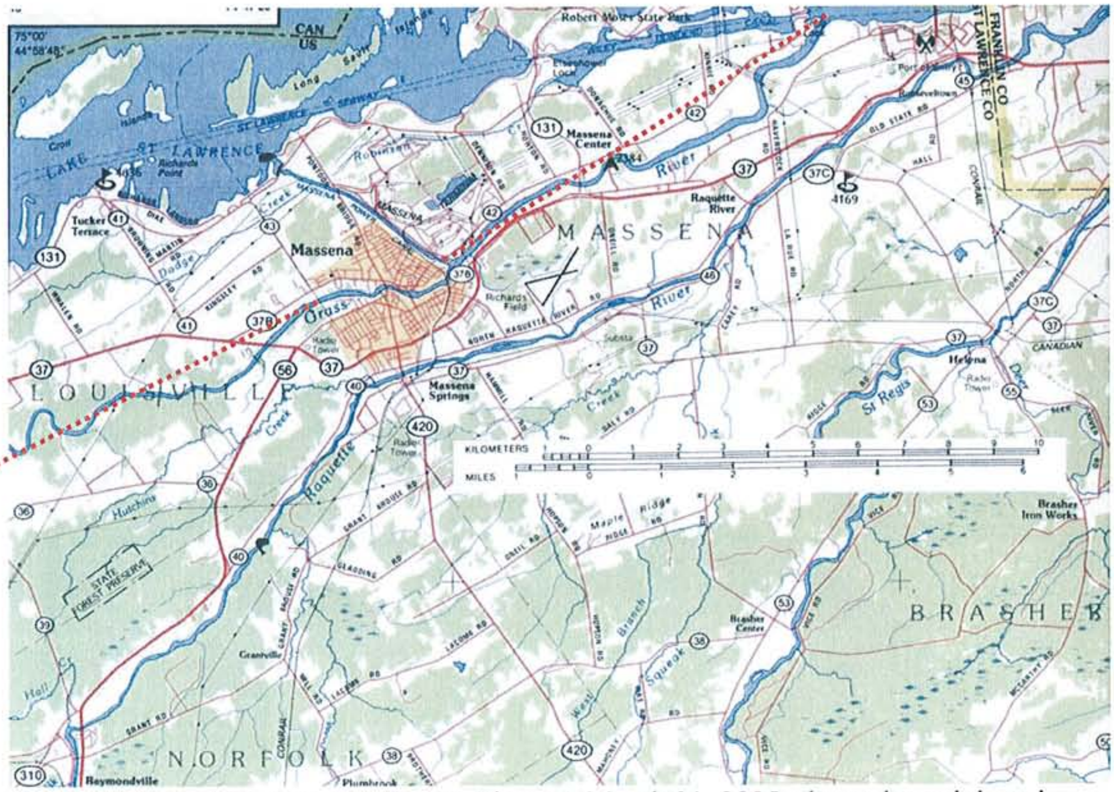


Fig. 1. Extent of ice cover on Grasse River on March 31, 2005, shown by red dotted lines

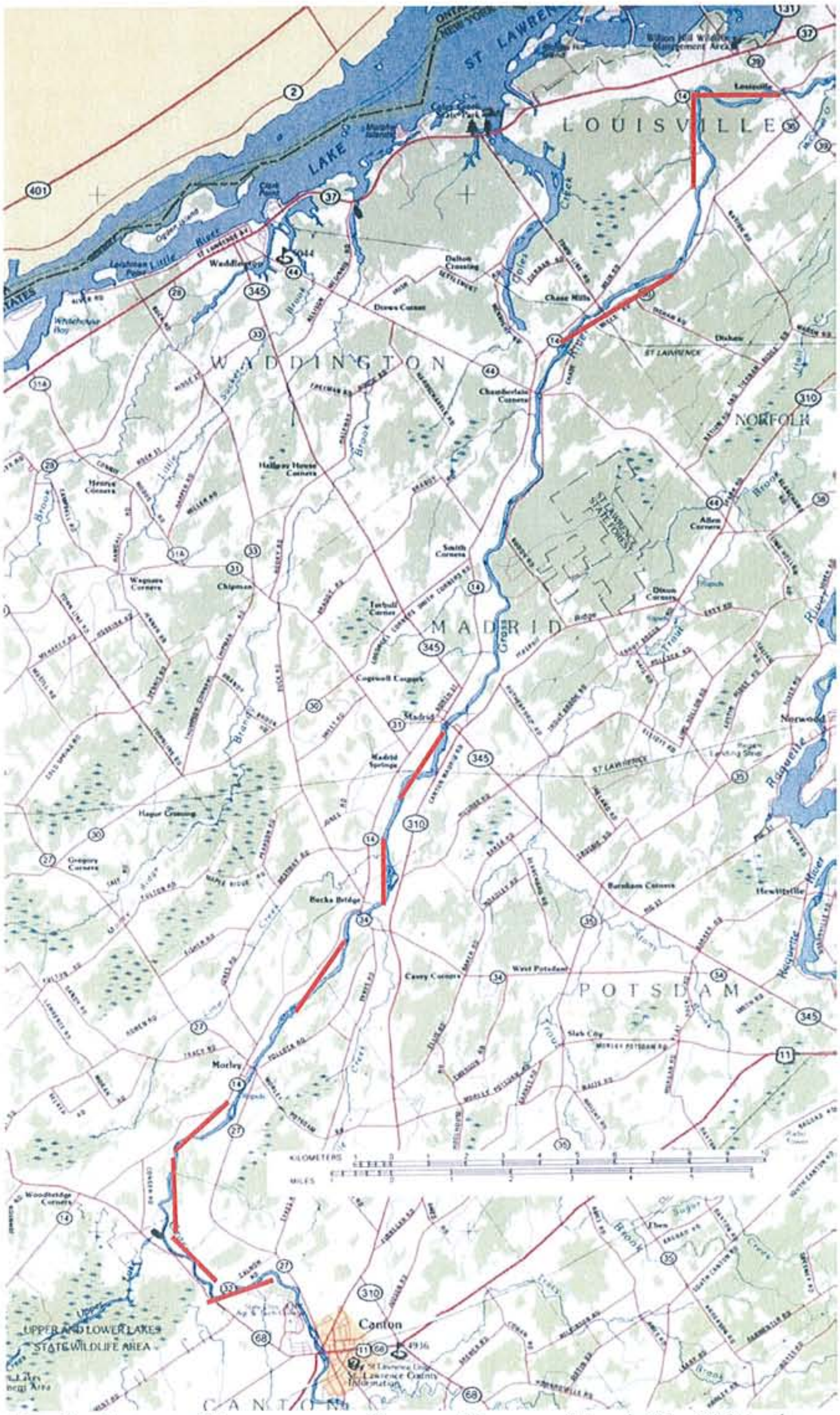


Fig. 2. Extent of ice cover on Grasse River on March 31, 2005, shown by red dotted lines

Fig. 3. Lower river sheet ice extends to mouth of the Grasse River, downstream of the Snell Lock.

Fig. 4. Lower Grasse River sheet ice.

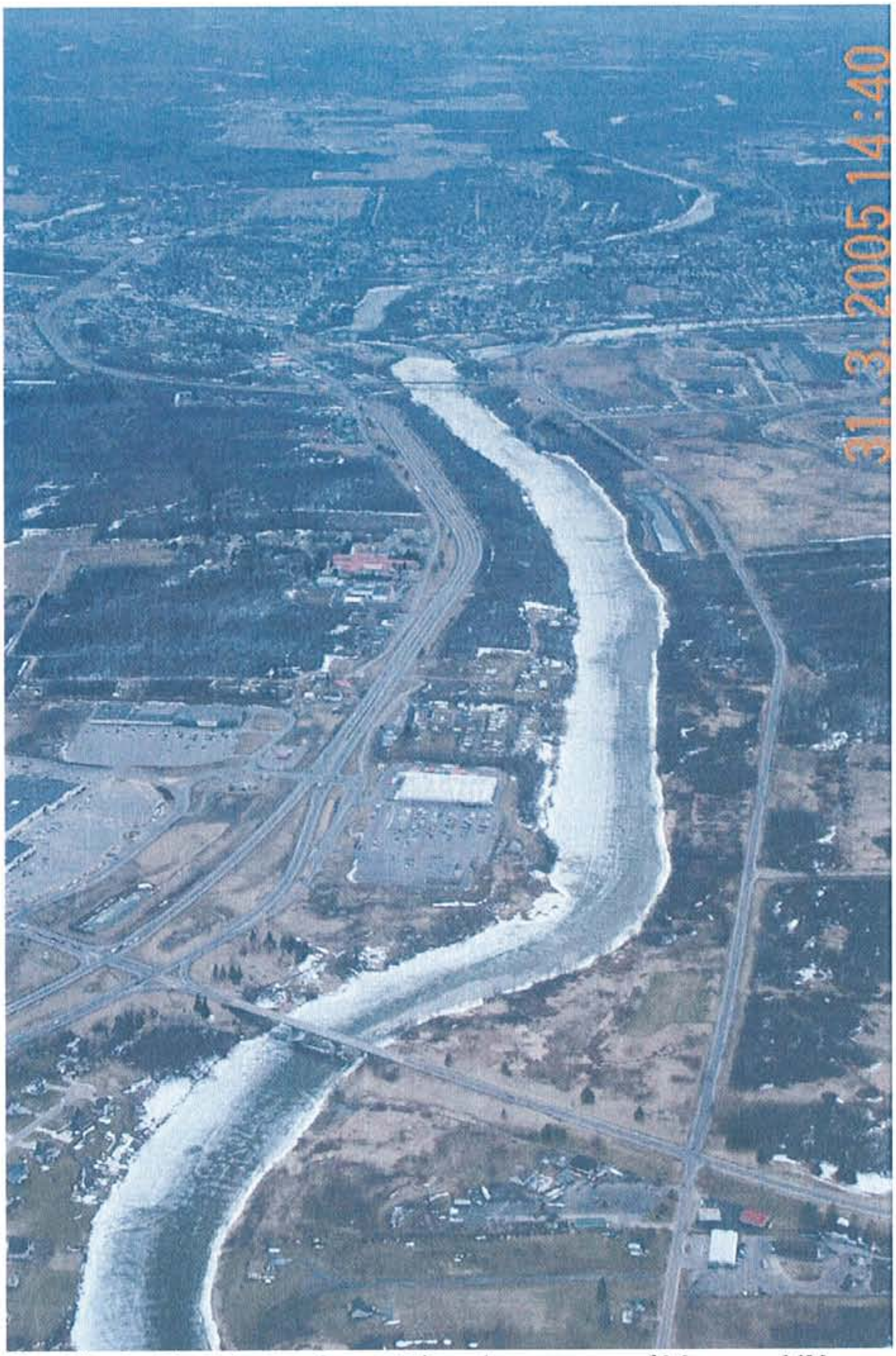


Fig. 5. Sheet ice on Grasse River downstream of Massena, NY.

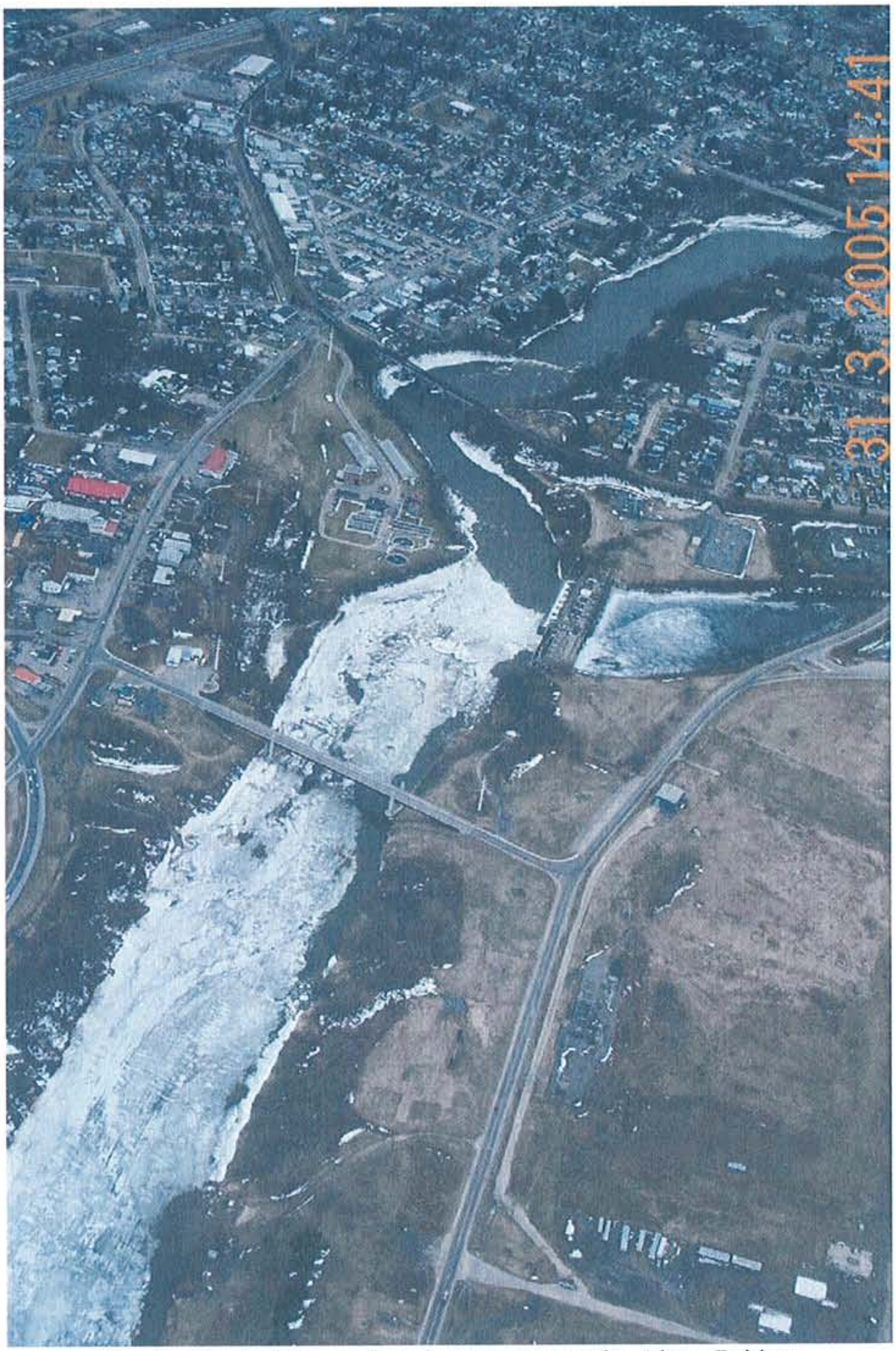


Fig. 6. Head of lower river ice cover near the Alcoa Bridge.

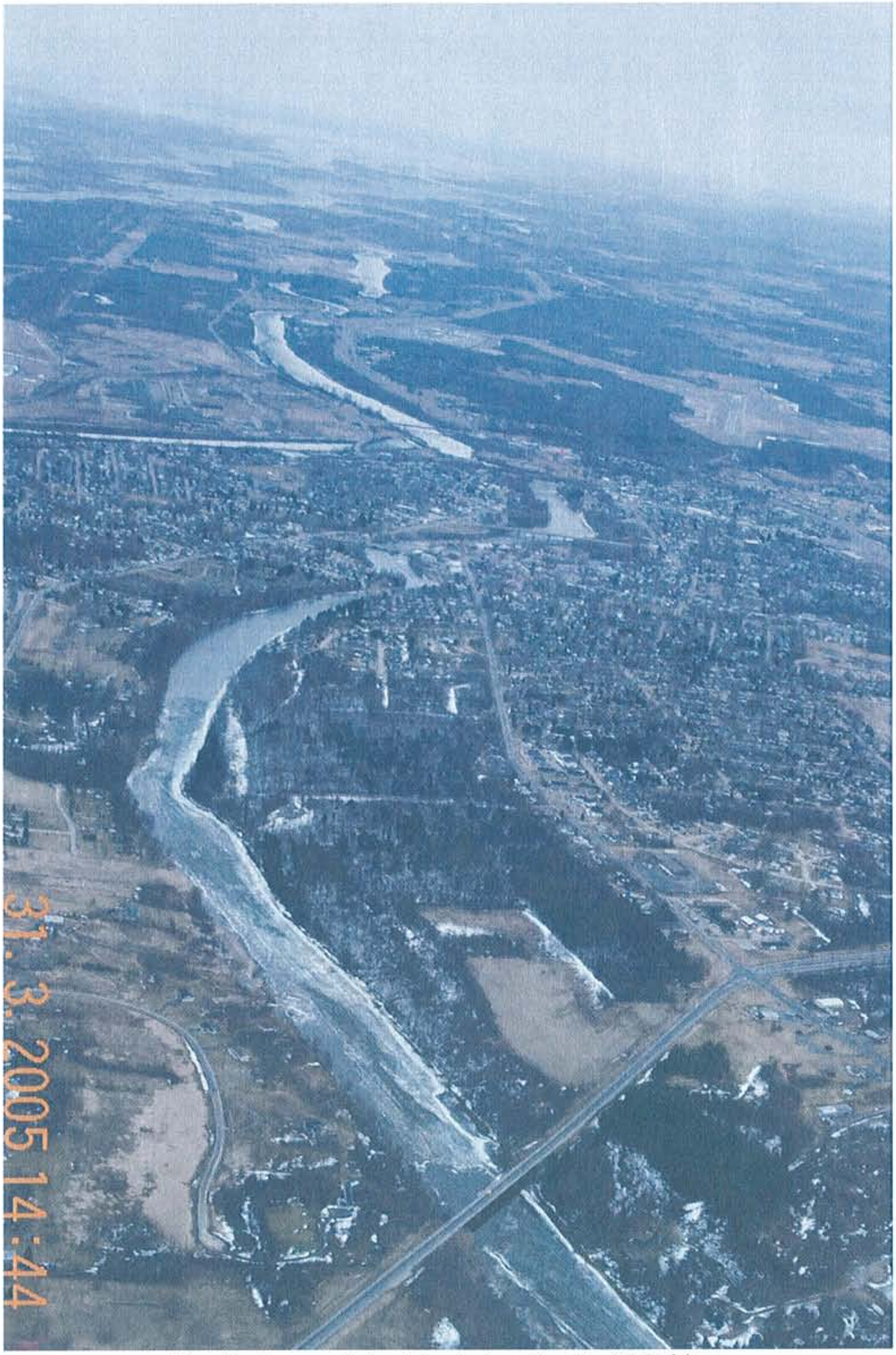


Fig. 7. Decayed sheet ice below the Rt. 37 Bridge.

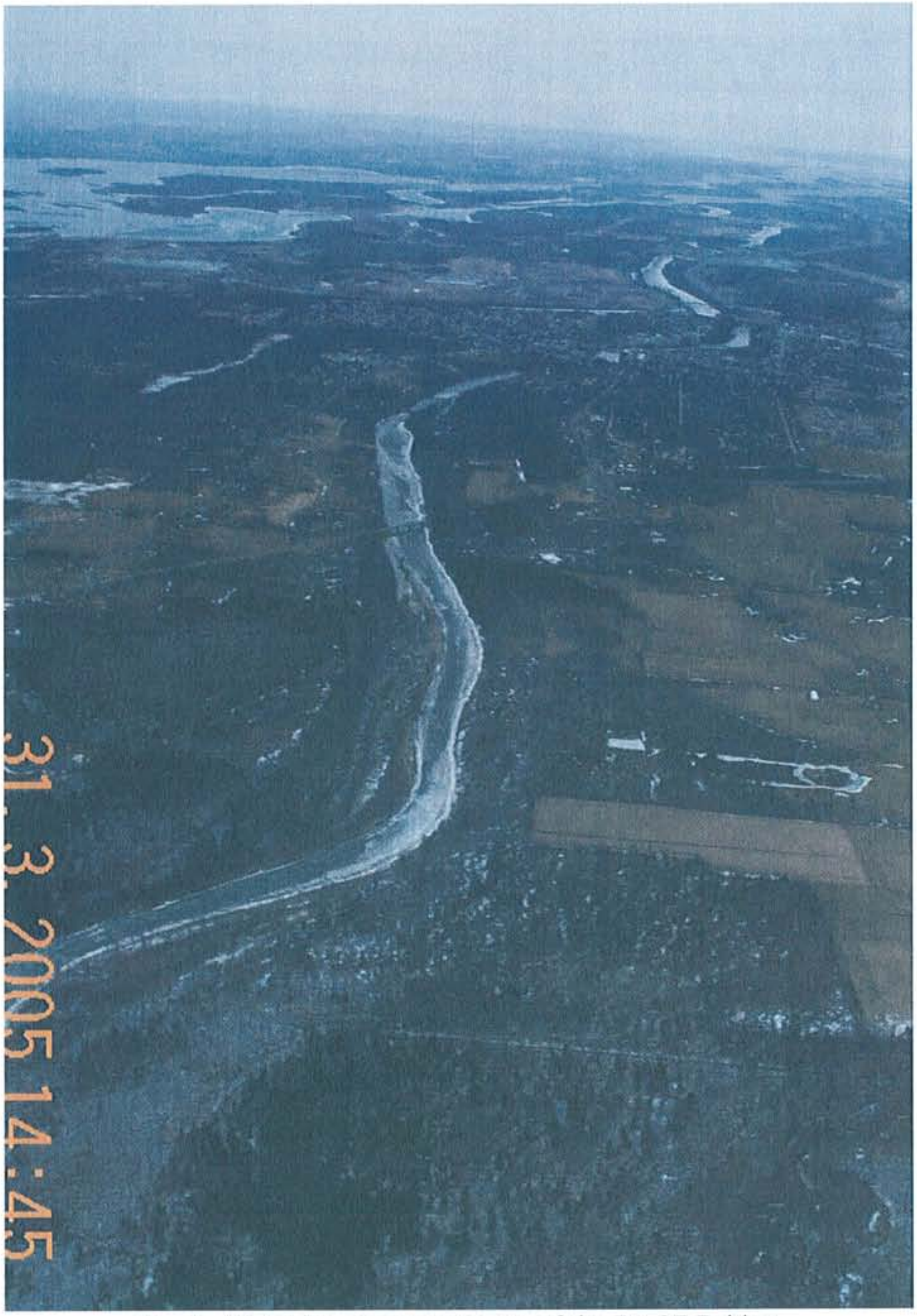


Fig. 8. Sheet ice cover upstream of the Rt. 37 Bridge.

Fig. 9. Head of the sheet ice cover at the foot of the Louisville Rapids.

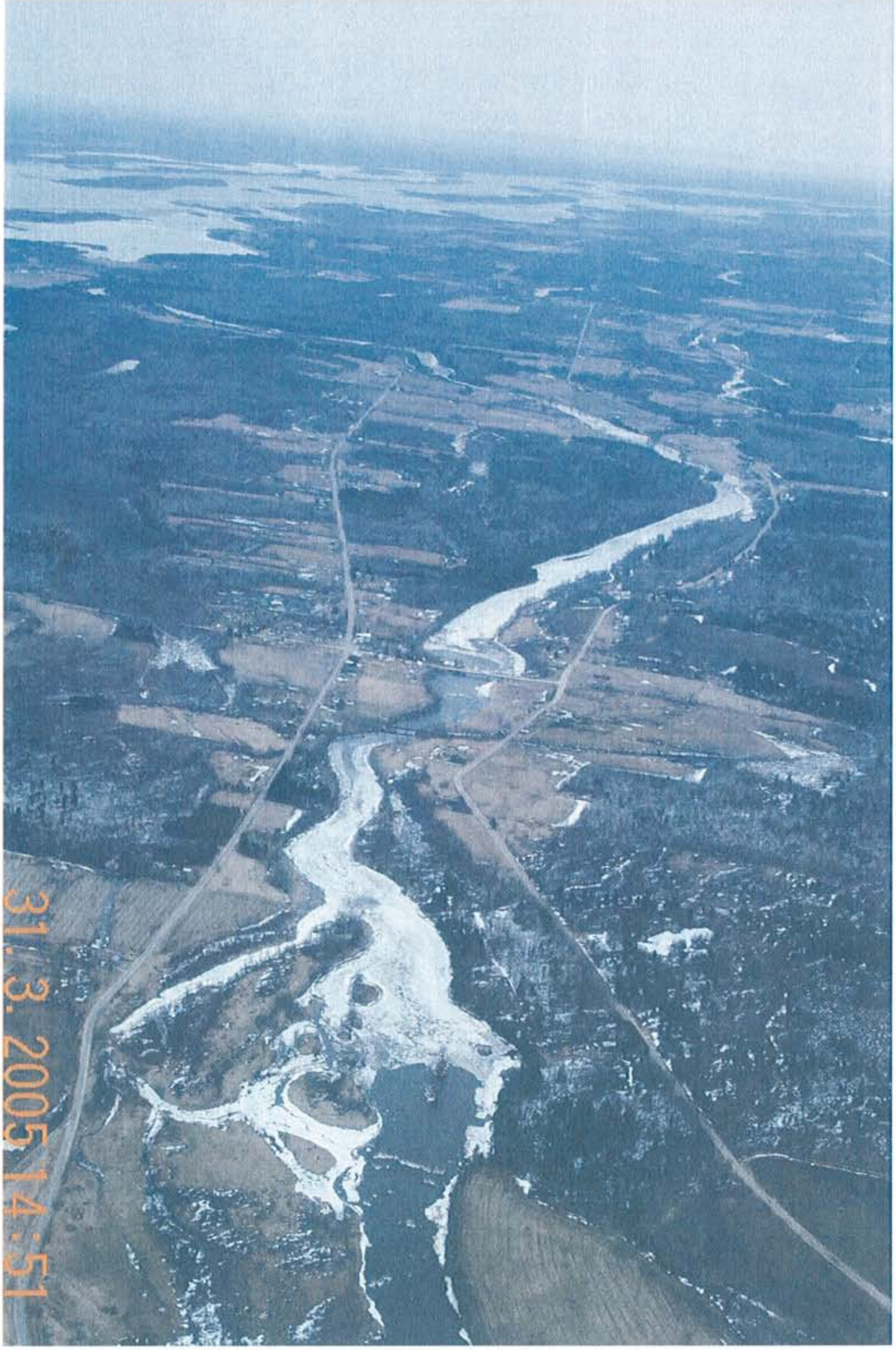


Fig. 10 Ice covers above and below Chase Mills.

Fig. 11. Open water at Chamberlain Corners looking upstream.

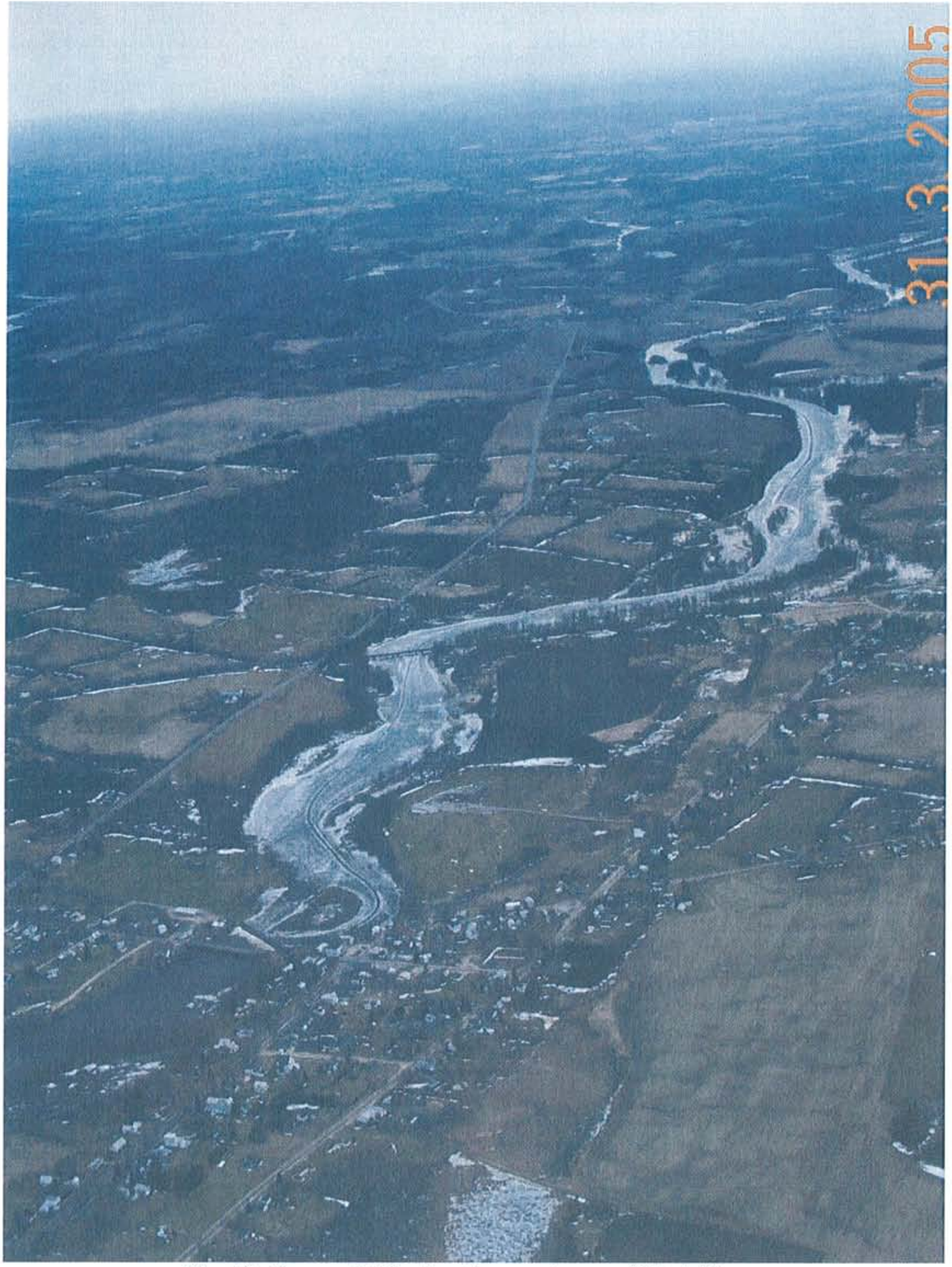


Fig. 12. Decayed thin sheet ice upstream of Madrid.

Fig. 13. Open water section at Morley, looking downstream.

Fig. 14. Ice-covered bend downstream of Canton.

Fig. 15. Sections of thin sheet ice upstream of Canton.

Fig. 16. Ice cover upstream of Pyrites hydro dam.